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MISTAKES IN THE RATING OF INCANDESCENT LAMPS.

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A 16 candle-power lamp is such a common article of commerce and in such general use that we all recognize it when we see it, or think we do, either by the size of its bulb or the length of the filament, or both. Very few people go beyond such mechanical identification except for the extra assurance they gain by a look at the manufacturer's label. Some, indeed, presume to tell that a lamp is of a given candle-power by looking at the brightness of its filament or by considering the general lighting of a room; but it need scarcely be said that an estimate formed by such a method is utterly worthless, since one is too much influenced by contrasts in brightness, or deceived by the temperature at

which a given filament is burned, to really tell anything at all about the candle-power.

The importance of exact knowledge of the candle-power of incandescent lamps is at last being recognized among lamp users generally. One of the signs of this in the present times is the great number of photometers recently set up and used outside of laboratories. Certain standard measurements are made with these, which are good so far as they go, but commonly many important things are quite passed by unnoticed. Not only should the user of incandescent lamps want to know that the lamps he buys really have the candle-power marked on them, and that they maintain their candle-power properly as they grow old in service, but he ought to know and fully understand a number of other things regarding the real candle-power and watts per candle-power of the lamps he uses. Some of these seem to have quite escaped notice, and their importance is so great as to merit careful consideration.

WHAT A 16 CANDLE-POWER LAMP OUGHT TO BE.

Let us first inquire into just what a 16 candle-power lamp ought to be. That it should be one which gives a light equal to that of 16 candles in the direction in which the light is useful seems a natural and fair definition. A little careful observation of lamps as they are installed shows that at least 85 to 90 per cent. of those used are put in place with base upward, or tipped end downward, and it is the light which comes from this tipped end of the lamp which is useful. In cases where the lamp is installed in a different position, either the lamp is subordinated to some artistic feature of the electrolier, or the lamp is installed "side on" to better keep it out of the way. So it comes that the light we ought really to want to know about, the light we ought to measure, is that coming out of the end of the lamp. Or at least it is sure that, if we call the axis of the lamp a line through it from the middle of the base up to the sealed-off tip, the light of value is that coming into space below a plane perpendicular to the axis, half way along its length. We can never use more light than

this, since for satisfactory lighting the sources must be above us, and in real service we make use of much less, as will be presently shown. Should we take the average candle-power of all the light rays into space below the imaginary plane just defined, this would be called the mean hemispherical candle-power, just as the average candle-power of all the light rays given by the lamp in every direction is called the mean spherical candle-power.

THE IMPORTANCE OF THE LIGHT FROM THE TIPPED END.

The placing of lights is to-day being made much more intelligently than by the old rules of so many 16 candle-power lamps per 100 square feet of floor surface, or per 100 cubic feet of room to be lighted. Some certain amount of illumination is now striven for, and a proper distribution of light rather than of lights is sought.

In a great deal of lighting one tries intentionally to give illumination concentrated about particular points. For example, in lighting a library it is the library table which is to be brightly lighted; other parts of the room need little more than the scattered rays otherwise useless, which reach them directly from the light source or after reflection. The light rays in poor planes and the reflected light which comes from the table, the walls and objects in the room, though contributing little to the important light, serve to break up shadows and produce diffusion. Almost the same thing would be true of the lighting of a bedroom, where the light should be concentrated about the bureau or dressing table.

In quite a different sort of lighting, still the same things hold true. Take the lighting of a factory or mill for example. The light must be on the machines or work, and be very good there. That which gives the room its general lighting is waste light from the light sources. To light the whole room as brightly as the machines would be too costly to be practical. For such lighting let us consider what rays are useful and what rays waste light. If the lamp hangs directly above the thing to be lighted, and its area be not more that 5 x 5 feet, no rays of light beyond 30° from the

axis of the lamp will be useful, and the higher the lamp is hung, the less the angle in which the useful light is found.

A second sort of lighting is that in which a uniform distribution of light is required, as in concert halls, or auditoriums of various sorts, and in shops for the sale of merchandise. A fundamental principle in this class of lighting is to use many sources of small candle-power each, all so placed that the light from them is directed downward, with perhaps a little diffused side light to break up the shadows, especially in small interiors. The lighting engineer is forced to use single lamps to procure this, except in large rooms, and they are nearly always installed base upward. The light from the tipped end produces the light of value.

A third sort of lighting is for decorative purposes, but that is so very especial and foreign to considerations of candle-power at all in most instances as to merit no consideration here.

The light below the lamp—that from the tipped end—is then the important and useful light in all practical cases. This is true, too, not only from the specific cases cited, but where large electroliers with many lights are used as well; for in such cases the lamps are usually flared out, with axes at some angle approaching 45°, in which case high candle-power from the tipped end and low from the sides of the lamp would contribute to a good, even illumination of the room.

The importance of procuring high candle-power below the lamp has been recognized a long time. But what expensive and roundabout methods have been taken to procure it! It is very common to use reflectors to increase the amount of light in the direction below the lamps. While reflectors have their place in lighting, and an important one, too, for most purposes they are exceedingly poor and are used in ignorance of the effects they produce or because no better device for light redistribution can be had. No matter whether the reflector covers the lamp or not, no matter whether it is of porcelain, a glass mirror, or a polished metal surface, it inevitably cuts the light off absolutely in some

directions and so directs it in others as to produce sharp shadows and brilliant lighting contrasts. In satisfactory lighting contrasts of light and shade are always avoided, and by producing diffusion most shadows are lost. Other devices, like McCreary shades and specially shaped incandescent lamps having a reflector incorporated with the lamp, have faults precisely the same as reflectors. Holophanes, with their prismatic and accurately formed surfaces, turn the light downward and at the same time diffuse it by refraction, so that on all artificial lights the distribution of the light, and the lighting therefore, is improved by their use. A holophane gives a redistribution of light immeasurably better than a reflector always. If an incandescent lamp is installed base down, holophanes or reflectors must be used on it or the lamp be valueless in supplying really useful light.

The common use of such devices is evidence that the ordinary incandescent lamp does not give as much light below it as is required there. Is there, then, a bad light distribution from them? An examination of modern lamps will tell us.

FILAMENT TYPES AND CANDLE-POWER DISTRIBUTION.

There are five different types of filament in use to-day by various prominent lamp manufacturers, and in most cases a filament type indicates the product of a certain manufacturer who has adopted that as the one used in his standard lamps. These typical filaments are enough different from each other to show interesting individuality. I have classed them as follows:

(*a*) Straight U-shaped filament; a type rapidly passing altogether out of use.

(*b*) Single curl filament; a type much used, having a circular loop in the filament midway of its length. This type was originally designed to render filaments stiffer and less liable to bend without an anchor, and also to shorten the lamp bulb. It was found to give a better distribution of light than type *a*.

(*c*) Long curl anchored filament; a type differing from

type *b* in that the loop is long in the direction of the lamp axis and is anchored to the part of the lamp where the leading-in wires pass through the glass.

(*d*) Double filament; a type which uses two filaments like type *a*, set so the current passes through them in series, the filaments being in planes approximately parallel.

(*e*) Double coil filament; a type like *b*, except that there are two turns in the coil instead of one.

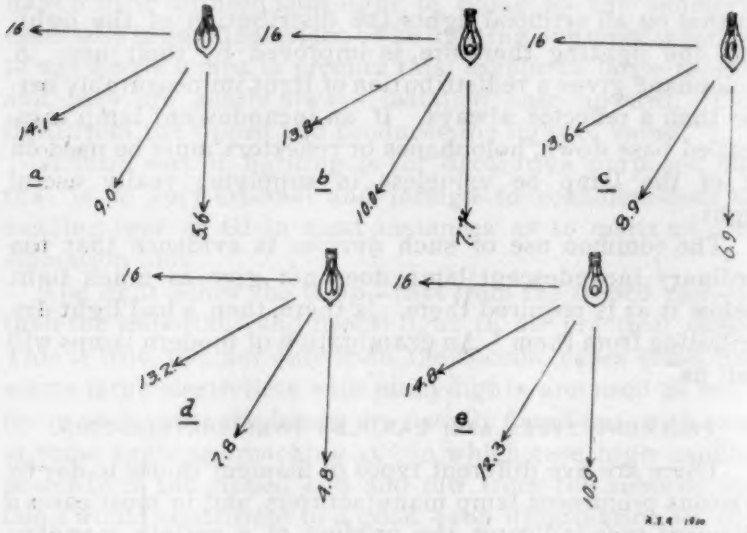


FIG. 1.

(*a*) Straight U-shaped filament.
(*b*) Single curl filament.
(*c*) Long coil anchored filament.
(*d*) Double filament.
(*e*) Double coil filament.

Showing average candle-power distribution from incandescent lamps of various types.

Besides being typical in the matter of general form, the light distribution observed from these various filaments is also typical. It is, however, considerably influenced by the exact relation of different dimensions in the filament itself used by particular firms; as, for example, the diameter of a coil or the spread of the filament shanks. Results below are therefore departed from somewhat if different makes of lamps had been used in the tests.

Fig. 1 shows average candle-power values from lamps of each of the different types. The arrows indicate the direction from which the candle-power was measured and the number gives the candle-power. These values are true averages of the types shown. In the averages struck no "freak" lamps were included. The five types are each represented by the product of some prominent lamp maker. All the lamps are rated 16 candle-power, all were in the standard bulb used by the manufacturer of a type, and, as it happened, all were 3·5-watt 110-volt lamps. A careful inspection of the figure shows one that the form of filament has a most important relation to the candle-power distribution, as of course it must, since the candle-power delivered in a given direction is determined almost wholly by the amount of filament length visible from that direction. A filament of type *a* shows only the end of the U when one looks in at the tip, and so the candle-power must be low, even if the U be broad. A double filament must show low candle-power for the same reason; and if the filament loops are narrow and the legs of the filaments straight, as they were in the lamps of the make tested, the candle-power may be even lower out from the tipped end than for a filament of type *a*. A filament with a coil in it shows much more projected length when viewed from the lamp's end, and so gives comparatively high candle-power in that direction. We see, then, that a 16 candle-power lamp is very different in the candle-power it gives in various directions and very different in a given direction with difference in type of filament. That lamp which gives most useful light is undoubtedly the best. Hence there is no question but that the 16 candle-power lamp with filament of type *e* is a far better lamp for general lighting purposes than any other. It is almost beyond belief that this has escaped notice in all the years incandescent lamps have been made and used, and yet it has been so. I first had my own attention called to the matter by the Shelby Electric Company, for whom I was making some tests of candle-power. It is their lamps which I show as type *e*. In an attempt to find whether in the past any one had attached importance to the light coming out from the

tipped end, I have been surprised to note how, over and over, this or that experimenter or lamp manufacturer has been on the verge of the discovery and then passed it by. One of the most recent cases I have noticed is that of a lamp manufacturer who advertised sign lamps with "all the light from the end," but seems never to have thought that this would be the right sort of lamp to use as his standard product.

Fig. 2 gives the relative amount of useful light from filaments of the different sorts, expressed in per cent. of the light given by the double coil filament (type *e*).

Filament.	Light in Given Direction in Per Cent.	
	Vertically Downward.	30° from Vertical.
Type *e*	100	100
" *d*	44·0	63·4
" *c*	63·7	72·4
" *b*	70·6	81·3
" *a*	51·4	73·2

Fig. 2.

The Shelby lamp (type *e*) for which data is given was made tipless; that is, the sealing off after exhaustion was not done as usual at the tipped end. The gain in candle-power by omitting the tip, so far as tests which I have been able to make indicate, is about 12 per cent. The loss in tipped lamps is probably due to light absorbed through the thicker glass at the tip and partly to reflection and refraction of light into useless directions which otherwise might have been saved to be useful.

What folly it turns out to be to use special devices to turn the light downward when the lamp itself can have the filament constructed so as to give a proper light distribution. A design of filament for incandescent lamps so they will give large candle-power from the tipped end is second in importance only to satisfactory efficiency and maintained candle-power with fair average life.

ILLUMINATION BY LAMPS USING FILAMENTS OF DIFFERENT TYPES.

A large amount of light streaming from the end of the lamp is only useful if it produces a proper illumination. In *Fig. 3* is plotted the illumination of a level surface 5 feet below a 16 candle-power lamp of different makes, the dis-

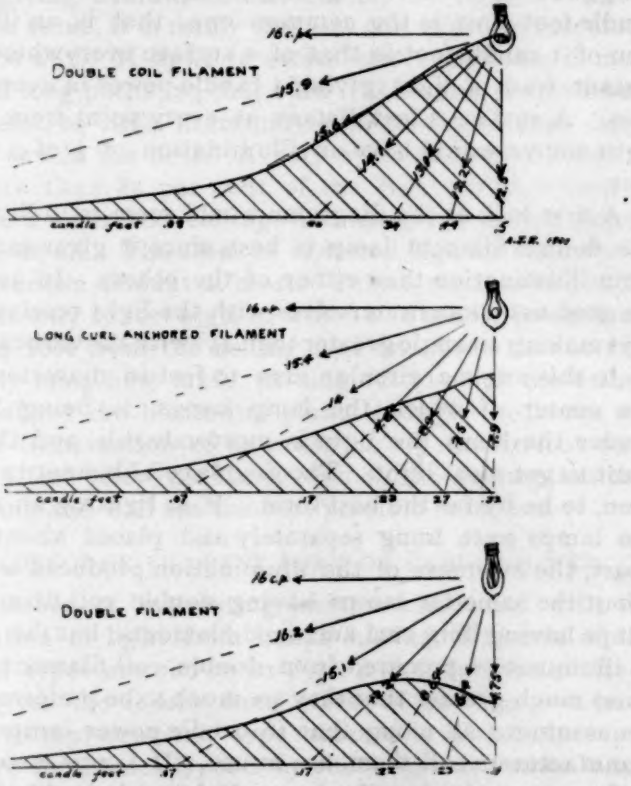


FIG. 3.—Illumination by filaments of different types.

tribution being shown one way out from the lamp only. A single representative lamp was taken of each of three important sorts and the candle-power as marked on the diagrams determined for the light given in each of the directions shown by the arrows. The illumination was then calculated in candle-feet, and this plotted vertically from

the base line. The solid curved line bounding the shaded area runs through the points so found, and all vertical distances from the base line give the amount of illumination there. Some of the values found are marked. Thus, for the long curl anchored filament ·32 of a candle-foot is procured at the surface illuminated by the ray giving 7·9 candle-power, ·27 by the ray giving 7·5 candle-power, etc. The candle-foot unit is the common one; that is, an illumination of 1 candle-foot is that of a surface everywhere 1 foot distant from a light giving 1 candle-power in every direction. A surface 2 feet distant at every point from such a light source would have an illumination of $\frac{1}{4}$ of a candle-foot.

A first look at the diagrams would seem to indicate that the double filament lamp is best, since it gives more uniform illumination than either of the others. In any case, we need not concern ourselves with the light received from rays making an angle greater than 45° with the vertical; since up to this angle a circular area 10 feet in diameter, above the center of which the lamp hangs, is being lighted. Under the lamp the light is most valuable, and there we want to get most light. The double coil filament turns out, then, to be by far the best form. If in lighting an interior the lamps were hung separately and placed about 6 feet apart, the evenness of the illumination produced would be about the same for lamps having double coil filaments, or lamps having long curl anchored filaments; but the amount of illumination procured from double coil filaments would be so much greater that they are much to be preferred. We are assuming all along that 16 candle-power lamps, as the manufacturers call them, are in use. If lamps were placed 15 feet apart, the distribution of light with double filament lamps would be very good if an even distribution is desired; but the average illumination would be low.

It is interesting to notice, in these plots of illumination, that after the 45° ray is passed the value of all types of filaments is about the same; and it should be noted that the illumination procured is very small. An illumination of $\frac{1}{10}$ of a candle-foot, for example, is that which one re-

ceives on a piece of paper held vertically more than 3 feet from an ordinary candle. Such light as passes out from a lamp in directions nearly horizontal or above the horizontal plane is useless except it is reflected back to the surfaces to be lighted or contributes to the general illumination by dispelling the gloom of the upper parts of a room and by giving a diffused character to the light. While it has such value, it is rarely that one can afford to use much light this way. If light is useful after reflection, it must travel in long paths; so that even if it reaches points where it is useful, so little illumination is produced that direct light is much the best. A very white surface will not reflect more than 85 per cent. of the light which strikes it, while dark walls and ceilings and hangings reflect almost no light at all. The item of reflected light is then one of very uncertain amount at most. Take a room in which the ceiling is only 12 feet high, in which a 16 candle-power lamp hangs 4 feet from the ceiling, and one finds that no rays from any lamp now made, passing out to reach the ceiling or wall above the horizontal plane through the lamp, will give an illumination of as much as ·05 candle-foot on a surface 5 feet below the lamp, even on the assumption that the ceiling and wall are the best possible reflectors.

INFLUENCE OF FILAMENT FORM ON CANDLE-POWER.

A number of interesting matters connected with the distribution of light from lamps having filaments of the different types are shown in *Figs. 4* to *8*, inclusive. Each figure gives the results from a test of one lamp—a lamp chosen to represent the type because it was truly representative mechanically, and by check against other lamps was found to be representative in light distribution. The rough sketch of the lamp on each figure shows very nearly the actual shape of the filament whose candle-power was measured. The left-hand sketch shows the lamp as it stood for measuring the horizontal candle-power at 0° and the right-hand figure at 90°. In all the candle-power diagrams distance out radially from the center of the diagram to the heavy curve gives the candle-power in that particular

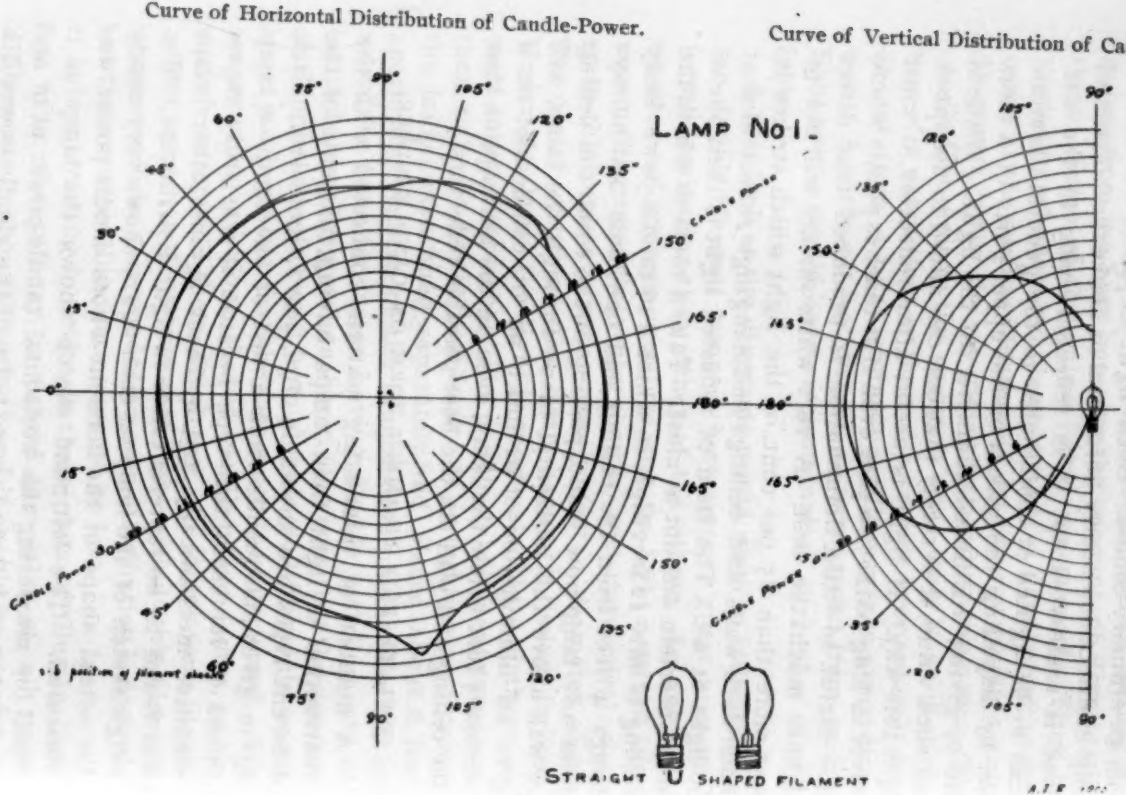

Curve of Horizontal Distribution of Candle-Power.
Curve of Vertical Distribution of Candle-Power.
LAMP No I.
Candle Power
Candle Power
STRAIGHT U SHAPED FILAMENT

FIG. 4.

FIG. 4.

Curve of Horizontal Distribution of Candle-Power.

Curve of Vertical Distribution of Candle-Power.

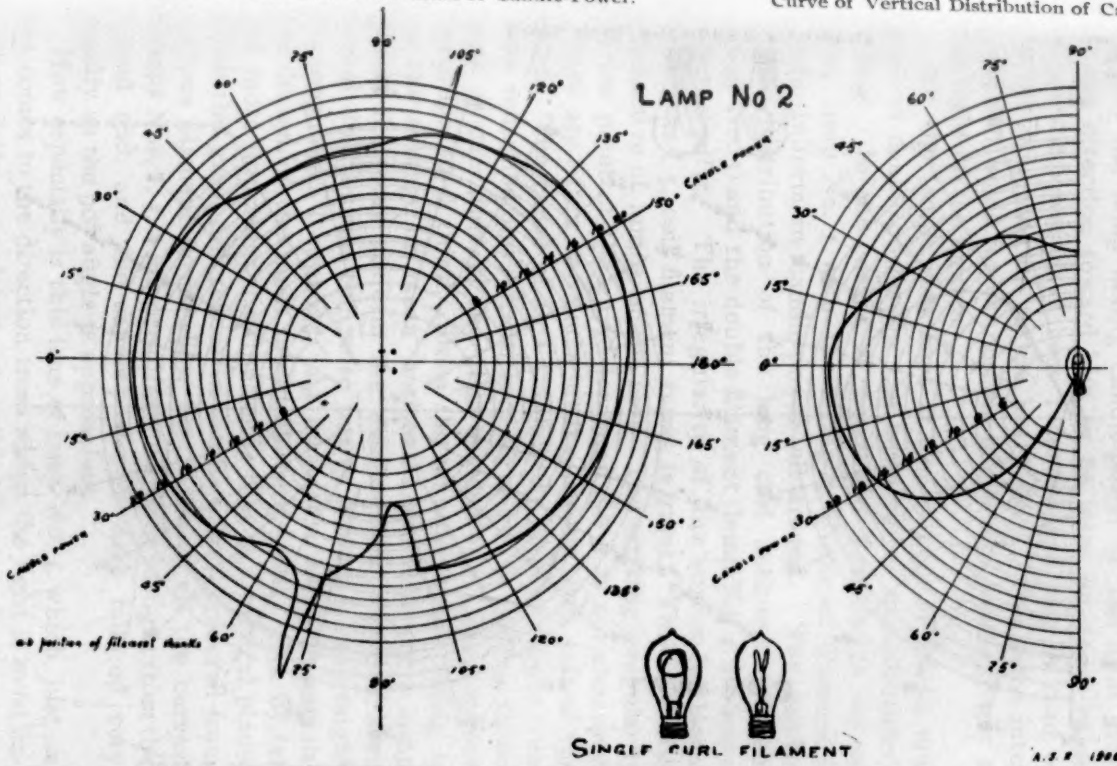


FIG. 5.

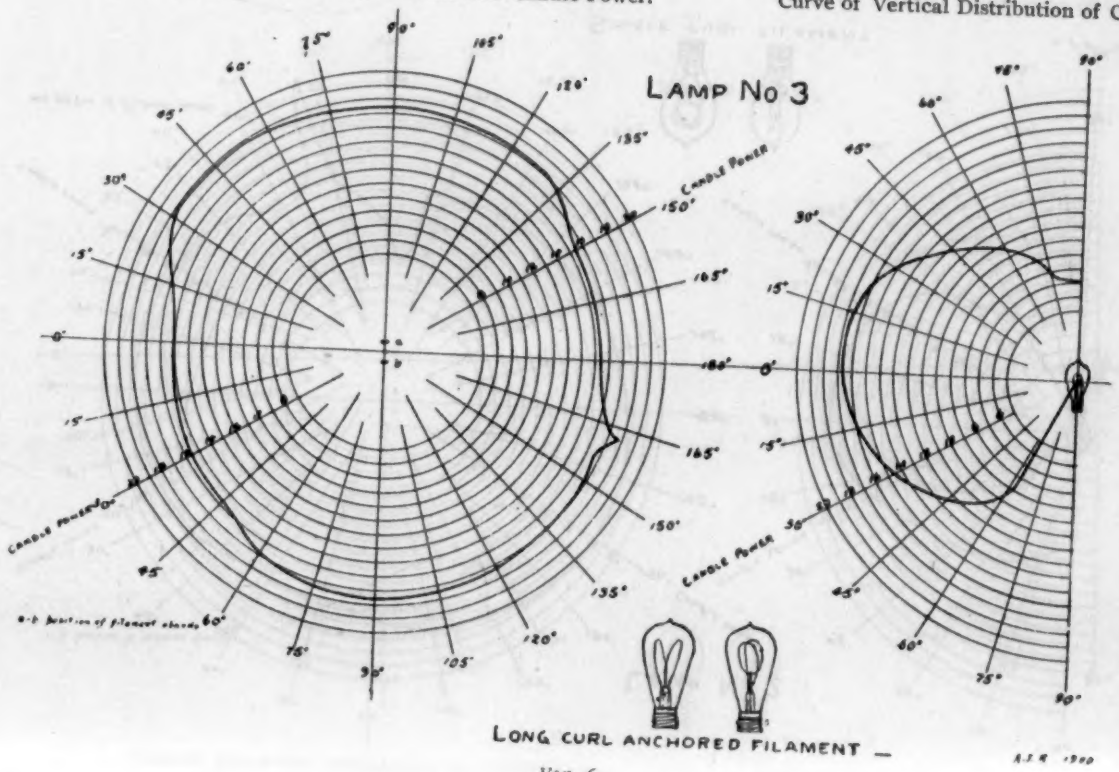

Curve of Horizontal Distribution of Candle-Power.
Curve of Vertical Distribution of Candle-Power.
LAMP No 3
CANDLE POWER
a-b Position of filament shown
LONG CURL ANCHORED FILAMENT —

FIG. 6.

radial direction. Thus, in the curve of horizontal distribution, if the lamp stood with axis vertical and one went around the lamp taking candle-power of the light given in the direction toward him as he went on, these values of candle-power have been recorded and can be read off on the diagrams up to the heavy line. The same interpretation holds for the curves of vertical candle-power at the right of the figures.

All the lamps were kept at the voltage at which they give 16 candle-power on the basis of the manufacturer's rating. In the curves of horizontal distribution we see that lamp No. 1 with the straight U-shaped filament is quite uniform in candle-power all around. The candle-power distribution of the long curl anchored filament (lamp No. 3) and the double filament (lamp No. 4) are somewhat similar. The irregularity of the curves for lamps Nos. 2 and 5, coil filament types, is great. This is always distinctive of lamps of the sort. The striking irregularity at one point of the curve for lamp No. 2 is not abnormal. There are often two such breaks, one on each side of the lamp. The cause of this irregularity may be due to complex reflection and refraction of light due to varying thickness or curvature of the glass enclosure. It has not been investigated, I think. Since the manufacturer's rating is on the average or mean horizontal candle-power a lamp gives, the more uniform the candle-power curve of horizontal distribution, the more nearly perfect a lamp might be considered, I suppose. At least, this seems to explain the design of the most recent filament forms. But by far the most important distribution is that in a vertical plane. Here the great differences in candle-power procured from various filament forms show best. Look at the curves. Lamps Nos. 1, 3, 4 are dreadfully deficient in light from the tipped end, and the candle-power of each falls off very rapidly as the 90° angle is approached.

How especially is this true of lamp No. 4, which, just as one comes to the direction from which the light is most important (between 75° and 90° at the tipped end), drops the candle-power down to less than five units. Most of the

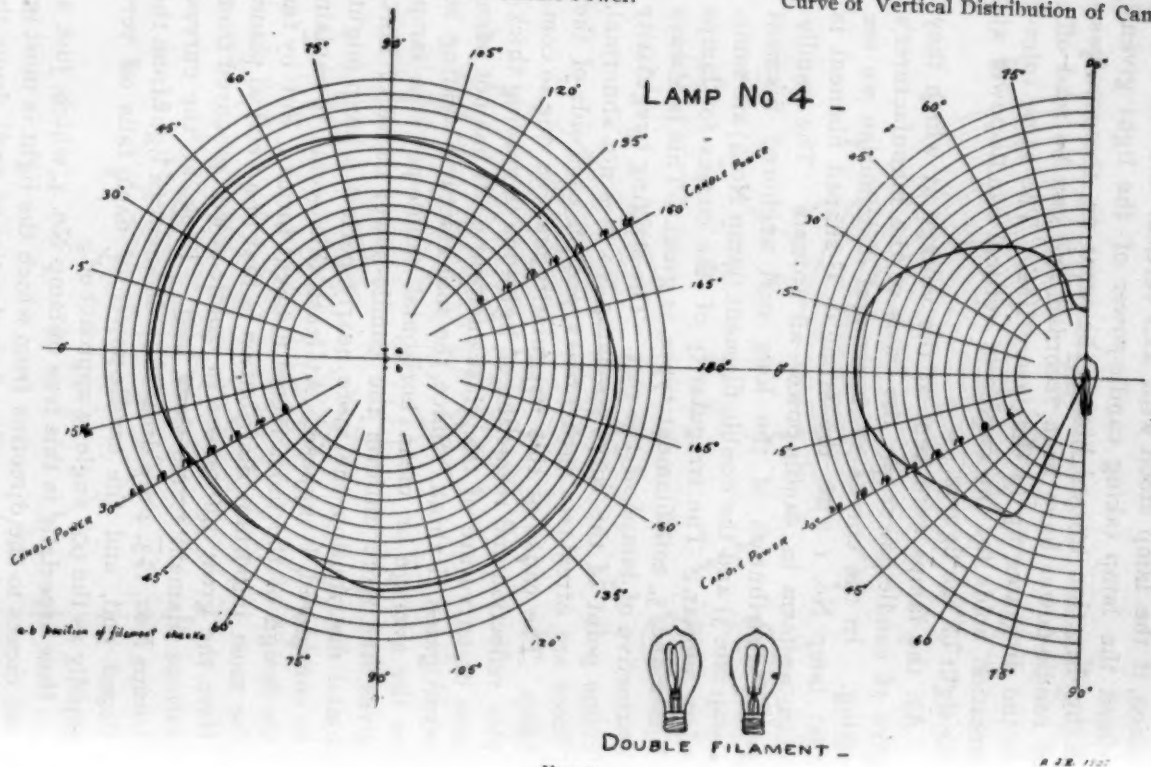

Curve of Horizontal Distribution of Candle-Power.
Curve of Vertical Distribution of Candle-Power.
LAMP No 4 -
CANDLE POWER
a-b position of filament shown
DOUBLE FILAMENT -

FIG. 7.

FIG. 7.

Curve of Horizontal Distribution of Candle-Power.

Curve of Vertical Distribution of Candle-Power.

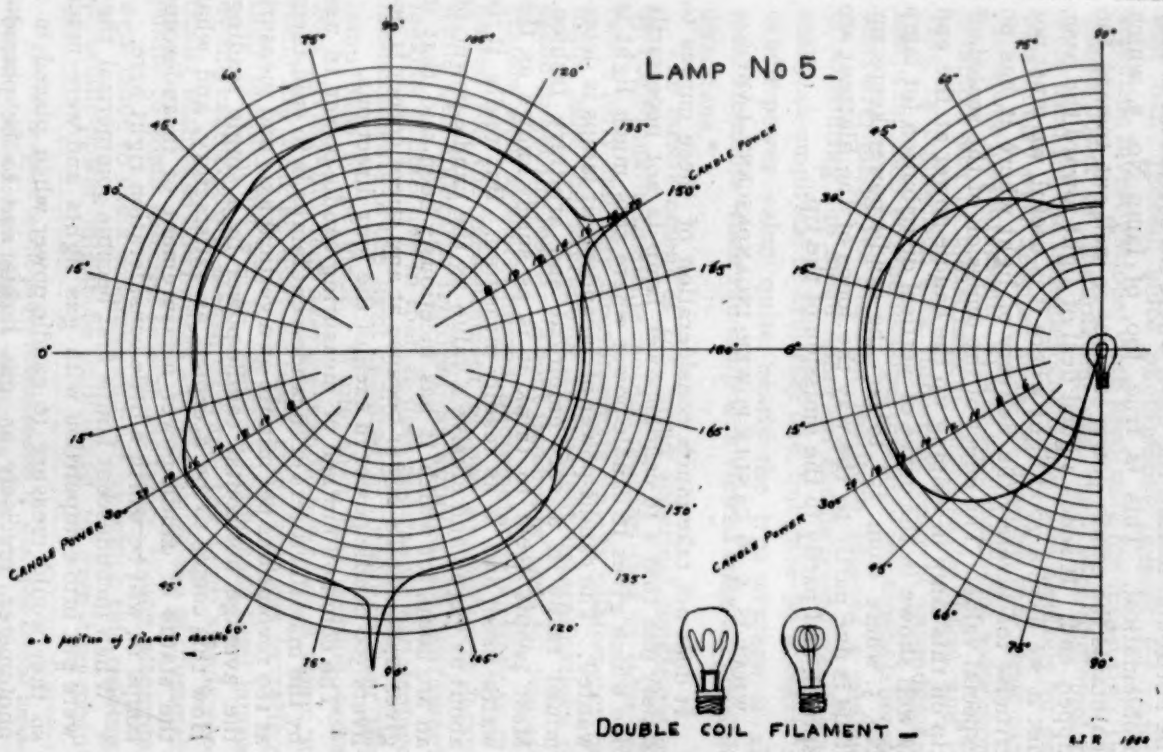


FIG. 8.

lamps, curiously enough, give most light in zones beyond the horizontal toward the base, where its usefulness is very problematical. This is true, too, of lamp No. 5, which maintains the candle-power it gives so well out toward the tipped end. It sends a good deal of light toward the base, but if we have a good light where it is useful, we must not criticise too severely the delivery of light where it has no especial value. The effect of the omission of the sealed-off tip on this lamp in helping up the candle-power at the end is well shown in the curve of vertical distribution for lamp No. 5, where from 75° to 90° the candle-power keeps up. This is due partly to the way the loops of the filament are spread, and partly to the omission of the tip.

WHAT IS A 16 CANDLE-POWER INCANDESCENT LAMP?

It does not take much consideration of these curves to satisfy one that a 16 candle-power lamp is not necessarily one which gives 16 candle-power where this much light is wanted. The candle-power of incandescent lamps is determined really in a very empirical and arbitrary fashion. Most people seem to think it is as surely known as the watts used, and is as readily measured. But really it is about as vague and elusive a value as the candle-power of an arc lamp, for which it has facetiously been said that it gives 2,000 candle-power because at any street corner it delivers 500 candle-power in each of the four directions.

The common method of measuring candle-power in use by the manufacturers of incandescent lamps is to spin them at 180 revolutions per minute on a vertical axis and measure the average horizontal candle-power by a single reading. How this comes to be accepted as satisfactory, and what the status of candle-power measurement of incandescent lamps is, will be worth a little consideration right here.

When incandescent lamps first became commercial they were put into competition with gas lights and were made so they would measure 16 candle-power when placed in a photometer, precisely as gas lights *had* to be placed—base down, and the old U-shaped filament with a plane

through the shanks of the U perpendicular to the photometer bar. Indeed, since photometers (except for purely scientific investigations) were used only for measuring the candle-power of illuminating gas, these very photometers were used for the incandescent lamps; and methods for gas photometry were adopted as far as possible into their candle-power measurement. It was soon clear that some more complete sort of measurement ought to be made, and in 1885, in connection with important tests of incandescent lamps for their economic value, probably the most elaborate tests ever made, the Franklin Institute adopted a method of measuring the mean spherical candle-power which was really an empirical or arbitrary one, but gave as a result a candle-power value quite nearly the true average of all measurements when the lamp was viewed from all possible directions.*

The measurement of the mean spherical candle-power by the Franklin Institute method requires that at least between forty and fifty measurements on the photometer be made, and the average of thirty-eight determinations is taken to get the result. About two hours' time for two operators with a well-equipped photometer laboratory is required for the measurement of one incandescent lamp, while the apparatus required, as supplied by instrument makers, is defective in that it does not enable satisfactory measurements of the light radiated in directions near the lamp base to be made. While, then, this method came near giving the real average candle-power of a lamp, it could not well be used by lamp manufacturers in rating their product, nor was it. Most of them rated their lamps by the candle-power measured when the lamp stands vertically with base downwards and the bar of the photometer points to some selected side of the lamp. Some attempts were made to use a constant number by which this reading of candle-power might be multiplied to give the mean

* The influence of candle-power measurements of gas upon similar measurements of incandescent lamps is well shown by the fact that the photometer expert of the Franklin Institute committee was Dr. Ward, the Philadelphia gas light photometric expert.

spherical candle-power for a given type of lamp, but without success in commercial usage.

In recent years, lamps have been measured by their mean horizontal candle-power and so rated. To save time, the manufacturer has lamps standing in the position already described, but has them rotating when the candle-power is measured. 180 revolutions per minute is a common speed, and the voltage marked on the label is that required to give 16 candle-power when the lamp is so rotating. The user who checks the manufacturer's product as it is delivered to him must perforce use the same method.

The National Electric Light Convention, not satisfied with the uncertainty of the methods in use, and in order to procure uniformity of standards and practice in rating lamps, appointed a committee, who made a report at the convention in June, 1897, in which they say that the mean spherical candle-power is the only proper and fair value to consider in comparing lamps. The practical measurement of this is so difficult, however, that a simpler method was recommended whereby the average luminous output of the lamp might be measured. The proposed measurement was to be taken "in the direction inclined 45° to the axis of the lamp, while the lamp is revolving upon its axis, the distance of the lamp from the photometric screen to be regarded as the distance between the center of the axis of its bulb and the screen. This will furnish a fair approximation to the mean spherical candle-power and reduce the amount of labor in measurement to the minimum." Two revolutions per second or 120 revolutions per minute was recommended as a speed of rotation.

A year later, in June, 1898, the same committee made a further report telling of tests made, confirming the committee's suggestion of measurement at 45° of inclination and making the proper speed 200 to 250 revolutions per minute. The committee was continued and made another report at the last meeting of the convention, but altogether on other phases of the subject—photometers, standards of candle-power, etc. Here the matter rests. In spite of the official adoption of the report by the convention, manufacturers

continue to rate their lamps by a measurement of mean horizontal candle-power with the lamps in rotation at 180 revolutions per minute. There is no photometric apparatus made which can be satisfactorily and continuously used for the measurement adopted by the National Electric Light Association, and if there were, the indefiniteness of the conclusions reached leaves much to be desired.

Candle-Power Taken.	Candle-Power.				
	Single U-shaped Filament.	Single Curl Filament.	Long Curl Anchored Filament.	Double Filament.	Double Coil Filament.
(*a*) At 180 revs. with axis vertical .	16	16	16	16	16
(*b*) Mean horizontal (standard method)	15·8	16·2	16·6	16·0	15·72
(*c*) Mean horizontal (from plotted values	16·0	16·7	16·7	16·1	15·6
(*d*) Mean spherical (standard method)	12·7	13·5	13·75	13·2	13·8
(*e*) Mean with axis at 45°	10·5	12·0	11·7	12·0	14·0
(*f*) Mean hemispherical.	14·3	14·5	14·6	14·0	14·5
(*g*) Mean within 30° from tip . .	8·7	10·3	8·7	7·9	10·9
(*h*) From the tip	5·7	8·35	7·05	4·8	10·1

Fig. 9.—Candle-power of lamps with different forms of filaments.

In *Fig. 9* I have set down a number of candle-power values for each of the five lamps of which some data was given in *Figs. 4* to *8*, inclusive. Each of these gives a value of candle-power by which the lamp might be called. The values were procured as follows: A lamp was set at 16 candle-power when rotating at 180 revolutions per minute with the lamp axis vertical, in the common arbitrary method, and for all measurements involved in the other tabulated values was held at that voltage. Values in line *b* were determined by taking the average of twelve readings as the lamp is turned, beginning with its standard position and at every succeeding 30°. Values in line *c* are computed from the curves in *Figs. 4* to *8* which take account of all horizontal candle-power variations. The line of mean spherical candle-powers is computed by the Franklin In-

stitute method. Notice how much less the real average is than the rated candle-power in each case and how this average compares with the rated value for each type of filament. Line *e* gives the candle-power these lamps should have been marked if rated by the National Electric Light Association's standard. The readings are not by a rotating socket, but averaged from readings made individually from the lamps tilted at the right angle. It will be noted that this agrees poorly with the value of mean spherical candle-power and bears no easy numerical relation to it. Line *f* of the mean hemispherical candle-power is to be compared with the spherical candle-power values, and this in turn with the line *g*, in which average candle-power is included every ray of really useful light. Line *h* is set down for comparison and to mention later. With such an array of candle-power values for each lamp, what is its candle-power?

WHAT SHOULD A 16 CANDLE-POWER LAMP BE?

Earlier it has been pretty thoroughly explained that the only sensible candle-power by which to call an incandescent lamp is that which is useful in producing illumination at desired points. Such a method has never been used in marking incandescent lamps for sale. It is strange how precedent binds us in everything we do. Here in the matter of incandescent lamp candle-power we are all tied to methods of designation which look back to photometric methods used for gas burners. True, mean spherical candle-power and rotation methods are distinctively electrical, but they first came to be of importance because incandescent lamps are so commonly placed in positions impossible to gas burners; and the rotation methods are used simply to save time in measurement, one reading taking the place of a dozen. It has already been explained that mean spherical candle-power is an impossible measurement for commercial purposes. Rotation methods are poor, too. Not only does the speed of rotation affect the result procured, but some of the best modern lamps produce such a flicker at the car of the photometer when rotated at standard speed (180 revolu-

tions) that not only is the making of an observation most trying to the eyes, but the observer can only make a rough guess for the position of his screen when a balance is obtained. A recent suggestion to choose such a speed for each lamp as just removes the flicker is impractical, also; for not only does it require an adjustment of speed with different lamps, but with many filaments high speed of rotation distorts the filament or even throws it against the glass, due to centrifugal forces brought into operation by the high speed.

What more rational, then, than to measure the lamp's candle-power looking in at the end? It is the light coming from the end which we make use of—which we are interested in. Then this is the light to measure, and that by which the lamp should be rated. Lamps measured thus are as comparable with each other as lamps measured any other way. The apparatus required to make the measurement would be very simple, for no rotating device would be required and the lamp need only be inserted in the socket without any care as to which side comes uppermost when its candle-power is determined, since the candle-power must always be read the same. Thus, readings of different observers would agree without respect to anything involved in the measurement, except the standards used and the personal element, which never can be eliminated. Such a radical change of method, however sensible the change, could not be made without the sanction and support of some of the large associations of electrical engineers. In the meantime, however, for eventually this method must certainly come to be used, all *lamp users* should, in addition to a measurement of candle-power in the conventional way to check up the lamps purchased, take a reading of the useful light out from the tip.

A 16 candle-power lamp should be one giving 16 candle-power from the tipped end. The horizontal candle-power might be considerably less and be irregular in different directions without altering the real value of the lamp. An ideal 16 candle-power lamp would perhaps be one which measures 16 candle-power from the tipped end, had 16 can-

dle-power as the mean horizontal candle-power, and was of nearly 16 candle-power mean spherical. Such a lamp could be turned into any position in an electrolier and still give an illumination equally as good as before and as well distributed.

In most lighting, also, the end of the lamp which has been called the tipped end all along should be tipless. Hold a piece of white paper below an ordinary tipped lamp hung with the tip down, as it commonly is, and the reason is unnecessary to state. Variations in thickness of glass and shadow cast by the tip make lines of light and shade that spoil all real value of light procured.

Watts Based on Candle-Power, as Stated.	Watts per Candle-Power.				
	Single U-shaped Filament.	Single Curl Filament.	Long Curl Anchored Filament.	Double Filament.	Double Coil Filament.
(*k*) At 180 revs. with axis vertical .	3·5	3·5	3·5	3·5	3·5
(*l*) Mean horizontal (standard method)	3·54	3·45	3·37	3·50	3·56
(*m*) Mean with axis at 45°	5·33	4·66	4·79	4·66	4·00
(*n*) Mean spherical	4·40	4·15	4·07	4·23	4·07
(*o*) Mean hemispherical	3·92	3·86	3·83	4·00	3·86
(*p*) Mean within 30° of tip	6·44	5·44	6·44	7·09	5·14
(*q*) From the tip	9·82	6·71	7·95	11·70	5·54

Fig. 10.—Watts per candle-power of 16 candle-power incandescent lamps on basis of different candle-power ratings.

Since the making of such lamps as these is doubtless but a choice of filament form and arrangement, let us hope it will not be long until there are some ideal lamps available commercially.

What is a 3·5-watt lamp?

So far no word as to the efficiency of lamps has been said. It does not directly affect the candle-power nor distribution of candle power. All the lamps mentioned above, for instance, were 3·5-watt 16 candle-power lamps. But why are they 3·5 watts per candle-power? Each lamp used

burned with a consumption of 56 watts. The efficiency or watts per candle-power is strikingly varied by the candle-power to which reference is made. In *Fig. 10* are set down the efficiencies of each lamp of the five types, calculated on the basis of the candle-power values in *Fig. 9*. A 3·5-watt lamp turns out to be one which uses this much electric power per candle-power if this is reckoned at its highest value, the mean horizontal. What a terrible inefficiency these lamps have if we calculate the watts per candle-power from the useful light or the light from their tips!

Type of Filament.	Cost of Current per 16 Candle-Power of Useful Light and per 500 Hours Service.
Single U-shaped	$9.43
Single curl	6.44
Long curl, anchored	7.62
Double	11.20
Double coil, tipless	5.32
Double coil (10 candle-power mean horizontal)	4.10

FIG. 11.

Lines *p* and *q* of *Fig. 10* give this. Lamps 2 and 5 are the only ones whose efficiency reckoned in a rational way is at all reasonable. The lamps of *Fig. 10* all were supposed to have the same average life and would not be very far different in maintenance of candle-power during life. If a lamp can be made which gives 16 candle-power out from the tip and burns at 5 watts per candle-power, we will have a lamp which is better than any now made. If its life is as good as the present 3·5-watt lamps, it would be a much better lamp than any we have now for all commercial usage. Keeping, however, to lamps now made, the table of *Fig. 11* gives the relative cost of current per 16 candle-power of useful light (light from the end) from each of the five different filament types now made. The computation is on the basis of 12 cents per kilowatt hour for electrical energy,

and the cost is per 500 hours of burning (the average life of a lamp).

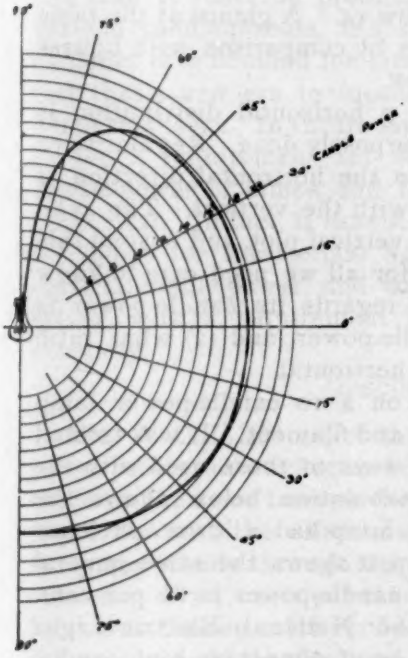
Since we only use electric current in incandescent lamps for the light we get, and since it is the cost of the light which is the vital, commercial problem, the table needs no comments to show which filament types are best; that is, which ones are most economical to use. I have put lowest in the table the cost of current per 16 candle-power of useful light from a standard 10 candle-power (mean horizontal) double coil filament lamp. This lamp gives 8·2 candle-power out from the tip. It is worth noting that a 10 candle-power lamp (so called), with this type of filament, gives as much candle-power out from the tip as any one of the other types which are rated at 16 candle-power. Hence, such a lamp using only 35 watts gives as much useful light as any of the other four types which require 56 watts.

A NEW FORM OF FILAMENT.

Since making the preceding tests there have been developments which are worthy of especial mention. A new type of filament for commercial lighting has come into being. The following matter describes its interesting features.

The Shelby filament, which is the most recent product of that company, has been designed and arranged especially to produce a high candle-power in the vertical direction. In *Fig. 12* is shown the average vertical distribution of candle-power from the new lamp. I call attention first to the arrangement of the diagram; I show the base of the lamp upwards, exactly contrary to the conventional arrangement of vertical candle-power diagrams since 1885. This method of plotting is natural and suggests at once the value of large candle-power downward (below the lamp). It is another step away from the conventions introduced into incandescent photometry long ago from gas photometer practice. I call attention next to the sort of filament and bulb tested; the rude sketch at the center of the diagram only suggests it. The filament itself is a good deal like

the old Shelby coil (see *Fig. 8* preceding), but with the circular coils flattened vertically, so that a much greater projected length of filament shows from the end. The bulb also is much flatter at the end than in other standard forms, and the light comes through it nearly at right angles to the glass. The lamps for which data are given were made tipless. The loss of light through the tips of lamps



SHELBY FILAMENT.

Curve of vertical distribution of candle-power.

This lamp burned at 116·3 volts using 61·6 watts.

Mean horizontal candle-power (At 180 R. P. M., 16·0.)	16·6
Mean vertical candle-power	14·9
Mean spherical candle-power	16·1
Mean with axis at 45°	16·5
Mean hemispherical candle-power	16·6

EFFICIENCIES.

Watts per candle-power reckoned on horizontal candle power	3·72
Watts per candle-power reckoned on vertical candle-power	4·13
Watts per candle-power reckoned on spherical candle-power	3·83
Cost of current per 16 candle-power useful light and per 500 hours of burning, at 12 cents per kilowatt hour	$3.97

having filaments so spreading as these would be very slight.

In the diagram there is to be noted a wonderfully maintained candle-power as one passes from the horizontal to the vertical direction. The lamp as I received it was one of a lot, none of which was marked for voltage, and I set it at 16 candle-power when rotating in the usual way, and made all subsequent measurements at the voltage so deter-

mined. The results set down are therefore on my rating, not on the manufacturers'. To understand the real meaning of the test data set down beside the curve of vertical distribution, comparisons must be made with similar values in the preceding part of this paper. The vertical candle-power (almost 15) is beyond comparison with that given by all filament forms except the double coil, which it even excels by 37 per cent. The mean spherical candle-power is also remarkable. The highest I know of in lamps rated in similar manner is below 14. A glance at the table of efficiencies of *Fig. 10* shows by comparison with figures here the economy of the lamps.

It may seem strange that a horizontal distribution is omitted in the test. This is purposely done. Regularity or irregularity of candle-power in the horizontal direction is quite unimportant compared with the vertical. The average horizontal is shown in the vertical plot, and beyond this it is quite unnecessary to go, for all we need care to know of an incandescent lamp as regards its candle-power is (1) what is the vertical candle-power, and (2) what ratio between this and the average horizontal.

A second test was made on a 10 candle-power lamp having the same form of bulb and filament. It was treated and rated in precisely similar ways to those used with the 16 candle-power lamps. A tabulation below shows the results procured. While the lamp had a lower efficiency than the 16 candle-power lamp, it shows the same general characteristics. The vertical candle-power is 86 per cent. of the horizontal, and by the National Electric Light Association's rating it would be of almost as high candle-power as if rated by the usual manufacturers' rotating method.

10 CANDLE-POWER SHELBY FILAMENT.

CANDLE-POWER.

Vertical candle-power	8·7
Mean horizontal candle-power	10·06
Mean spherical candle-power	9·78
Mean with axis at 45°	9·87
Mean hemispherical	10·05

EFFICIENCIES.

(Watts per candle-power.)

On vertical candle-power	4·7
On horizontal candle-power	4·05
On spherical candle-power	4·17

Cost of current per 16 candle-power useful light and per 500 hours service, $4.50.

The above lamp used 41·8 watts at 112·35 volts.

I take it that the production of such a filament, such vertical candle-powers and such efficiencies as these are evidence of a demand for lamps of the sort. I cannot but feel that a new era in incandescent lighting has dawned when this is so. In future lamp specifications we may look to see a requirement set down as regards the vertical candle-power of lamps, and the ratio of this to the mean horizontal. In fact, it cannot be long before specifications for lamps for commercial lighting will ask for a certain vertical candle-power, and watts per candle-power on this rating, with a requirement as to a minimum horizontal intensity.

DISCUSSION.

MR. W. C. L. EGLIN, of the Philadelphia Electric Company, presented a reflector lamp, which, he explained, was made on the same lines as the Shelby lamp described in the paper, but with the effect magnified. The light from this lamp was wholly through the end, and he claimed for it an efficiency of 1·5 watts per candle-power in the direction the light was thrown. He further stated that the coil form of filament was old, having been used in some of Mr. Edison's early lamps. Mr. Eglin went on to say that the light out horizontally from an incandescent lamp, which strikes the walls, is important and necessary in producing good illumination, and so the horizontal candle-power should be considered. He attached no great value to initial measurements, and questioned the life and maintenance of candle-power of the Shelby coil filament.

MR. FRANCIS HEAD, of the Union Traction Company, in reply, stated that he had carried a number of such coiled

filaments through a life test, and they had proved fully equal to any of the other makes.

PROF. ARTHUR J. ROWLAND, author of the paper, said that the paper carefully avoided the question of life and maintenance of candle-power, since the intention was to deal wholly with light distribution. The light distribution must remain the same throughout the life of any lamp, without respect to decrease in candle-power. He admitted that the coiled filament in the old type Shelby lamp was not new, and called especial attention to the circumstance that the advantages it gave had never been observed, for this form alone gives a good candle-power distribution. He further said that the light out to the walls was, of course, a good thing, in order to have them properly illuminated; also, that the light reflected from them may be of a little use when the lamps in service give but low candle-power out from the end opposite the base. As a matter of fact, the useful illumination produced by light reflected from the walls is almost negligible, since it has to pass through the long distance to the walls and back again. Its only value is to break up shadows and aid diffusion, as shown numerically in the paper. Moreover, if this kind of light is useful, the Shelby coil filament has as much light to send out to light walls and for reflection as any other, while the direct light from it is much greater. A reflector lamp has use in certain specific instances: for example, to supplement general lighting over a desk when it takes the place of a lamp with such a reflector as a McCleary shade. It is not practical for commercial lighting, however, since it limits the light absolutely to the direction in which the reflector sends it, and produces strong, sharp shadows.

REFLECTOR LAMPS.

Compared with others in preceding paper by Prof. Arthur J. Rowland.

There is nothing new in reflector lamps; they were introduced into this country some years ago by a foreign manufacturer, and more recently have been produced by several American manufacturers, and classed with their special

lamps. Very recently the General Electric Company has brought out a reflector lamp of the same general style as those which preceded it.

For certain purposes a reflector lamp is useful. It may supplement general illumination and give concentrated light to advantage where this is desired, but it cannot be successfully used for commercial lighting for several reasons.

The light is all directed one way and absolutely cut off from every other direction. This gives one a bright spot of light under the lamp, but dark spaces between, around and above them—quite dark except for reflection from the few objects illuminated. Nothing can be more trying to the eyes than to look from brightly lighted objects to those not lighted at all and back again.

An ordinary reflector lamp, acknowledged to consume 50 watts, is extravagantly used for lighting even though the efficiency may be 1·5 watts per candle-power in the direction in which the light is thrown, for the reason that it illuminates only a small area. With it general illumination would be necessary at additional cost.

A reflector lamp combines a reflector and a lamp in one. While the combination may cost less than lamp and reflector bought separately, when the filament burns out the reflector is gone too; hence, at the price these lamps are offered, they are too expensive for general use. Separate reflectors are much to be preferred where it is really necessary to use them.

In comparison with other lamps which are used regularly in commercial lighting, the reflector lamp suffers. It gives no horizontal light at all, and the importance of a certain amount of this light is recognized by all good lighting engineers. Any lamp which gives enough light in the vertical direction to be economical, and gives light out besides in the directions which assist general lighting and diffusion, is far superior to a reflector lamp. It is found that the old double coil filament has these features, but it is greatly exceeded by the new Shelby coil, as is shown by photometric tests.

Whether a lamp which gives 16 candle-power horizontal

and 16 candle-power vertical is better than one which gives 6 candle-power horizontal and 16 candle-power vertical is an open question. Every one must agree that there is some limit below which the horizontal candle-power of a lamp should not be decreased, and this is before the zero point is reached.

If reflectors over lights to throw the whole light flux in the vertical direction are necessary for any sort of lighting, that lamp is best which uses a form of filament giving high candle-power in the vertical direction without the reflector. By reflection one adds only to the direct light. Of two lamps having a given light flux to reflect, that one having most initial candle-power in the direct rays will have the brightest light after a reflector is put in place. A Shelby coil filament turns out then to be better than any other form when used with a reflector or shade as well as without.

Stated Meeting, held Wednesday, May 9, 1900.

ALUMINUM:

CONSIDERED PRACTICALLY IN RELATION TO ITS GENERAL APPLICATION IN THE ARTS AND MECHANICS.

By Joseph A. Steinmetz,
Member of the Institute.

"As light as air! As bright as silver! Impossible of tarnish! As strong as steel! Cheap as clay!

"The great new white metal aluminum. Houses, bridges and locomotives to be built of it. Iron and steel, metals of the past; with the great 'Aluminum Age' drawing upon us."

Such picturesque and startling remarks were not at all uncommon ten years ago, and even more recently in the most prominent local papers and technical journals.

To the unthinking mind, it was perhaps quite believable that aluminum, the laboratory curiosity costing dollars per ounce, should excite wild dreams of coming wonders when, almost over night, the discovery and successful application

of the electrolytic methods of reduction put the price of this unknown metal to almost as many cents per pound.

But nothing could have contributed more to its disadvantage and disaster of its industrial development. Years of time and tons of samples have not yet served to disillusionize the world of these disastrous notions, and hundreds of thousands of dollars have been ruthlessly wasted in trying to force the metal to perform impossible services, devoid of wisdom or foresight.

The purpose of this paper is to briefly enumerate those uses of aluminum that have proved satisfactory and extensive, with the view of encouraging further applications along kindred lines, and to speak a word of caution regarding improper uses of the metal, so that disaster may be avoided, and to save aluminum from further damage to its chemical and physical reputation. From the fact that the aluminum output is almost doubling from year to year, it is almost as impossible to cover the uses of the metal in detail as it would to trace the myriad uses or applications of any particular metal, such as silver, copper, brass, zinc, tin-plate or galvanized iron.

A satisfactory classification is nearly impossible, hence the thousand and one uses of the metal will be jotted down in a running list as the suggestions come to mind.

Upon the use of aluminum in the metallurgy of steel we will not dwell, save to briefly remark that for this purpose many hundreds of tons of metal are annually consumed.

The aluminum is added to molten steel in proportions of a few ounces to the ton of steel, in the making of ingots and billets.

Larger tonnages are treated in the process of making steel castings by adding the aluminum to the molten mass before pouring. It has also been found of great advantage, to insure the making of a perfect casting, to insert small scraps of aluminum in the mould at such places and corners and cores where difficulties threaten.

Many tons of aluminum are yearly used for the making of patterns. This is indeed a most correct use to replace the old heavy brass gates of patterns with the light-weight

aluminum, stiffened with about 5 per cent. of zinc and a like amount of copper. The advantages of these light-weight patterns are manifest. The men at the benches can mould more forms in a given time and with less fatigue. The patterns, weighing but one-third as much as brass, can be handled and stored more readily and cheaply. The express charges upon return of patterns are greatly reduced —an item of considerable magnitude in an active foundry.

Immediately the very large use of aluminum suggests itself for models and salesmen's samples. Particularly will the hardware traveler see the boon of this, and many of our largest houses have full lines of salesmen's samples, replacing the old line of ironwork or nickel-plated brass, at a reduction of 60 per cent. of weight, and of no increase of cost.

Not long ago a large foundry of Wilmington, and, later, a Philadelphia foundry, had some large iron castings to make, the yokes of cable roads, great iron pieces spreading the full width of the track and supporting the rails, and carrying in their middle the conduit through which the cable ran. These castings were made from wooden patterns, which caused much trouble by chafing and wearing in the sand, and warping and springing out of alignment. At the suggestion of the writer these patterns were duplicated in aluminum, and all difficulties were thus transformed into unpleasant memories, and the work fell out good and sound and true.

Until recently aluminum has not been employed as an active competitor of brass and copper on account of its higher comparative price, but to-day aluminum is cheaper than copper, considered bulk for bulk. Copper is three and one-third times heavier than aluminum. Taking, therefore, copper at its present market price, and increasing by this factor, it will appear that aluminum is cheaper, a fact which should open many channels of new application for aluminum.

One thing that has figured seriously to the disadvantage of aluminum, and, indeed, has quite precluded it from many excellent fields of use, is the lack of a good, cheap, easily-worked and permanent solder.

It is true that there is a most excellent solder upon the market, invented by Mr. Joseph Richards, of your Institute, but this solder is difficult to apply, and it is frequently beyond the ability of the ordinary tinsmith to secure a satisfactory joint.

There are several reasons for this lack of success. Not keeping the work hot is the chief cause of the solder mushing and making a rough, dirty seam. It is very often true that the peculiar pattern or intricate design of the piece makes it impossible to keep the work hot at the points to be soldered. Then, too, the quick formation of a film of oxide upon the aluminum, unless removed by scratching or filing, figures to the disadvantage of a solder by not permitting it to take a firm hold upon the parts to be joined.

Wherever possible, then, it is earnestly suggested to make joints by crimping or lock-seaming or by riveting, or, better yet, to avoid all joints by spinning or drawing up the shape to be made, whenever its contour will permit of such practice.

The old saying that "the best joint is no joint at all" holds good here conspicuously.

A few remarks relative to the growth of the aluminum industry, with comparative figures, will prove of interest.

The following table shows the aluminum production of the United States and of the world, expressed in metric tons (2,000 pounds):

	U. S.	World.	Per Cent. in U.S.
1889	21·6	70·9	30
1890	27·9	165·3	17
1891	68·2	233·4	29
1892	118·1	487·2	24
1893	154·4	716·0	22
1894	250·0	1,240·9	21
1895	417·3	1,418·2	29
1896	590·9	1,659·7	36
1897	1,814·4	3,394·4	53
1898	2,358·7	4,500·0 (est.)	52
1899	2,948·4	6,000·0 (est.)	49
1900	4,000·0 (est.)	7,500·0 (est.)	53

Those returns marked estimated (est.) are the best which can be conjectured from available data. The aluminum in-

dustry is growing most rapidly in France and in the United States. Canada will enter the list of producing countries next year, with a plant of 5,000 horse-power, and will add 1,000 tons each year to the world's output.

Presuming that the total amount of aluminum produced last year was used for the specific purpose of electric conductors, then the 6,000 tons of aluminum would displace 12,000 tons of copper, or a like amount of aluminum sheet would be equivalent to 20,000 tons of sheet copper, were the specification for culinary and cooking utensils.

These comparative figures emphasize the important position that the metal has assumed.

Considering the United States alone, of the metals produced here in 1898, only pig iron, copper, lead and zinc were produced in greater quantity than aluminum, and only these, with the addition of gold and silver, surpassed it in the value of the output.

If we desire to manufacture a given object of metal, we can make it cheaper in aluminum than in anything else, excepting iron, lead or zinc, to which might be added, among composite metals, tinned and galvanized iron.

These are the only metals left for aluminum to compete with, and its greatest struggle in the future will be against tinned and galvanized iron. Dr. Richards believes that when the market price of aluminum reaches 15 cents per pound (probably in the next decade), it will compete actively with these common metals, and by 1925, when it will probably reach 10 cents per pound, its only practical rival will be steel.

The middle of the twentieth century will see steel and aluminum standing side by side as the most useful of the useful metals, aluminum having by that time developed many peculiar alloys enhancing its physical properties and largely increasing its field of application.

The plants now producing aluminum are those of the Pittsburg Reduction Company, at New Kensington, Pa., and Niagara Falls, New York; the British Aluminum Company, of England; the Aluminium Industrie Actien Gesellschaft, at Neuhausen, at the Falls of the Rhine, in Switzerland; the

Société Électrometallurgique Française, at La Praz; the Société Industrielle de l'Aluminium, at St. Michel, in France.

There are also several large plants projected and in course of construction, notably upon the St. Lawrence River, in Canada, and at Rheinfelden and Salzburg, in Germany.

The Hall patents under which the Pittsburg Companies are producing expire in 1906, and by that time other competitors will be actively engaged in adding to the domestic tonnage.

Then, too, it is more than likely that attempts to repeal the import duty of 8 cents per pound will soon be made, as this duty is no longer necessary for the protection of our infant industry, particularly in view of the fact that a large percentage of the aluminum produced in this country is exported to Europe, leaving the supply of metal at home quite inadequate for domestic needs.

Some years ago, when aluminum was thrice its present cost, the proprietor of a certain brass foundry in Philadelphia had the courage to back up his convictions that the metal was ideally suited for bath-tub work.

Some years even before this, a maker of bath-tubs had attempted its use in sheets for this purpose, by lining the old wood-box tub with aluminum sheets joined by crimping and soldering. They had to abandon the project after repeated failures to secure a tight seam and joint, lacking a solder that was easy to work, and that would readily run out a long seam.

These same lines were unsuccessfully attempted by other bath-tub makers, who had met with some encouragement by avoiding the soldered seam by flanging the sheets and clamping the edges thus formed between an iron frame, which acted as the support to the basin body.

The brass foundry previously mentioned followed radically different lines and made a single sand casting of the complete tub with its roll rim, the same pattern as we now see in enamelled iron, upon which it is almost impossible to improve, unless perhaps by a stamped sheet-steel tub or one of moulded glass.

This cast tub weighed about 150 pounds, and the rough sand casting was ground smooth upon the inside and around the rim by use of an emery wheel upon a flexible shaft, after which the tub was polished bright upon a rag buffing wheel.

A perfect casting was difficult to obtain, due to blow-holes and shrinkage cracks and sinks, and the difficulty of this piece done in practically pure aluminum can well be appreciated by those familiar with foundry practice.

The effect thus obtained was decidedly brilliant, and most pleasing, but the tub failed ignominiously in the test of time and use. The alkali of the soaps utterly destroyed the luster of the finish, and ate deeply into the body of the metal, marring and pitting it beyond measure. Thus it came about that another use for aluminum became impossible of realization.

The same general observations apply to the large list of plumbing fixtures of aluminum evolved at about this time, such as faucets, chains, handles, soap-dishes, basins, and many standard shapes in nickel-plated brass, which were quickly retired as brief experience proved their worthlessness.

A most excellent use for aluminum is found in the making of steam-jacketed kettles and cauldrons for boiling of syrups, fruit juices, honey and wax, as well also as for certain acid work for which the peculiar chemical properties of the metal specially adapt it.

An example of this might be cited in Mr. Levy's nitric acid atomizer for zinc etching, a great improvement over the old acid bath for obtaining quick action in making etched plates for printing. There has recently been completed by a coppersmith of Newark one of the largest aluminum kettles ever constructed; the hemispherical bottom or bowl measuring 51 inches across its diameter with its flanged edge, and 30 inches deep, was cold hammered and formed up out of a flat circle 68 inches in diameter, and the upper band or tubular body was curved around out of a flat sheet measuring 13 feet 8 inches long by 14 inches wide. The kettle was hammered out of $\frac{1}{4}$-inch stock, and the bowl

was much more readily shaped and more responsive to the tools than even copper.

The purpose of these large boiling kettles is for melting wax for the cylinders of the Edison Company's phonographs, as the wax cylinder material seemed to attack iron and copper kettles, whereas the aluminum boilers are entirely unaffected.

In the electrical field aluminum is forging ahead rapidly into significant prominence.

It was singularly opportune for its introduction for electrical purposes that the price of copper advanced just at that time when the processes of making aluminum in increased quantities and at reduced figures of cost had been satisfactorily installed, and when new uses and new fields were being eagerly sought; for immediately many careful experiments were undertaken to determine the possibility of substituting aluminum for copper, and these investigations promise to produce most encouraging results. Comparative tests are now being made by the Chicago Fire Alarm Service between copper wire and aluminum. Number 10 wire was used and the preliminary tests before erections showed that the tensile strength of the copper wire was greater, size for size, but not so great weight for weight. The copper wire showed a greater elongation and endured without rupture a greater number of twists—in fact, twice as many as aluminum.

To secure further data under the actual service conditions, the Chicago line will be given a winter's test, and has been strung in the stormiest section of the city, and where it will also be subject to the smoke and gaseous fumes arising from the locomotives passing in that section. The results of this service test will be made the subject of a report this spring by City Electrician E. B. Ellicott, of Chicago, to his Board.

The Western Union Company has several miles of aluminum wire in use now for over two years, and is carefully compiling the physical data necessary for a consideration as to its merits in comparison with copper and iron.

A very interesting report relating to the "Tests and Cal-

culations for a Forty-Mile Aluminum Wire Transmission Line," by Mr. E. A. Perrine, as erected and conducted by the Standard Electric Company, of California, is printed at length in the *Aluminum World* of November, 1899.

General Greeley, chief of the Signal Branch of the U. S. Army, had several outfits of aluminum portable field lines in use in Cuba during the recent war, and he reports that they were very satisfactory and particularly advantageous, owing to the light weight of the coils of aluminum wire.

The main electric conductors in use at the reduction works at Niagara Falls are made of large aluminum bars many square inches in area, and have been giving satisfactory service for years.

To some extent aluminum has been used for commutator segments, but the difficulty in wiring up due to the different metals in contact caused serious discouragements. Blades for switchboards have been successfully manufactured.

The advantages of aluminum for use in the making of culinary and cooking utensils were early recognized, and the new metal bids fair to excel copper in this line of development; in fact, many hundred tons annually are now consumed in the successful manufacture of such articles.

The early exploitation of this field was most discouraging, owing to the fact that the manufacturers of cooking utensils understood the peculiarities of the metal no better than the consumers who purchased the articles for use, and the utensils were generally seriously abused, battered and neglected, the universal idea being that aluminum was quite indestructible, no matter how abominably treated. The utensils were allowed to take care of themselves; they were ground and scratched with sand-soap and often washed in lye, which, being one of the solvents of the metal, caused rapid disintegration.

These early attempts to introduce aluminum cooking utensils were made at a time, several years ago, when copper was less expensive, and when enamelled iron and tinned and steel articles were infinitely cheaper.

These adverse circumstances tended seriously to the retirement of aluminum from this field, but later develop-

ments, such as the fall in price of aluminum, and the heroic efforts of our pioneer manufacturers quickly regained the ground thus lost, and forged rapidly ahead to well-merited success, for now aluminum cooking utensils, household articles and culinary shapes, for home, institutions and hospitals; field equipments for the army and outfits for the navy, and the innumerable uses heretofore supplied by copper, tin sheets and enamelled iron are divided with aluminum, and the new metal bids fair to win first honors.

Among some of the advantages possessed by aluminum over the other metals might be cited its higher heat conductivity; its light weight, bulk for bulk; the fact that it creates no poisonous salts or oxides when used in the preparation of fruits and vegetables and other possible combinations dangerous with copper or tin.

A very large use of aluminum in forms of caps and covers, stamped out of sheet metal for sealing catsup, mustard, fruit, jams and jellies, and various lines of such goods, has been lately developed, the advantage of price and absence of dangerous corrosion or acid action making aluminum an ideal metal for these purposes.

In Europe the peculiar advantages of aluminum have been recognized for a much longer time than in America, and a number of the largest manufacturers in England and on the continent are making complete lines of utensils.

The recent South African war has created a tremendous demand for aluminum field cooking and messing outfits, thus spreading the fame of aluminum and knowledge of its advantages for portable gear among a class of men who will understand and appreciate them.

A most interesting account of the British army equipment will be found in the March number of *Aluminum World*, of the current year.

The German army, as well as the field forces of other continental powers, are thoroughly equipped with aluminum, and the dead weight per man of superfluous ornamentation and equipment has been considerably reduced, tending greatly to increased efficiency as a fighting unit.

In the recent Arctic explorations, in the gold-seeking ex-

peditions into the Klondike and Alaska, in the journeys into the Dark Continent, aluminum equipment has played a prominent part; Mr. Wellman built aluminum sledges for transporting his supplies over the ice; the Alaskan gold miners took in many light camping and cooking outfits, and Dr. Carl Peters had with his expedition an aluminum steam launch in portable sections.

Five years ago the well-known shipbuilding firm of Yarrow & Co., of England, built the first aluminum torpedo boat, and while a second craft of this description has not been since constructed so generally of aluminum, yet two of the latest additions to our navy, the torpedo boats "Craven" and "Dahlgren," have their observation towers, hatch covers, galleys, cowls and many minor parts made of aluminum.

These boats were built by the Bath Iron Works, of Maine, and the aluminum details of construction, embracing the use of rolled angles and structural shapes, plates and riveted work, were conceived with the approval of Chief Constructor Philip Hichborn, of the United States Navy, who looks forward with interest to the tests of time and the wear and tear of service to demonstrate the practicability and adaptability of aluminum for ship construction and fittings.

The American sloop yacht "Defender" was built of aluminum plates from water line to deck level, the submerged plating being of bronze, which arrangement tended to considerably lower her center of gravity, insuring increased stability.

These aluminum plates, which were carefully and thoroughly painted, gave good satisfaction and are still in service. Certain plates in the stern had to be replaced, as well also as smaller parts and fitting, due to corrosion and electrolytic action and wear and tear.

In general this application was highly satisfactory and encouraging.

Aluminum powder and thin beaten leaf are now largely used for securing decorative effects in the arts, as silver paint, and for printing and bookbinding, having

almost entirely replaced the silver bullion leaf formerly used.

The powder is also mixed in the form of a paste for ink for printing coarse cotton tinsel fabrics, in gaudy design for Oriental trade.

A paint called in the trade pegamoid, aluminoid, or aluminum bronze paint, is largely used for coating architectural ironwork, lamp-posts, letter-boxes, elevator grilles, and cages, and kindred applications, and has proved highly satisfactory.

Overtures have been made to the Public Building Commissioners to paint the outside of the Philadelphia City Hall Tower, to restore it to an aluminum luster as originally intended, and far brighter and more durable than the dismal slate-blue of the unknown electro deposit now upon the ironwork.

Aluminum powder has found an excellent and successful use as a mixture for making photographic flashlights, being cheaper than magnesium and devoid of the pungent odor or unpleasant smoke incident to the combustion of the old magnesium powder.

A recently developed and tremendously successful application of aluminum is in flat, smooth plates for use in lithographic printing. The thin aluminum plates make excellent impressions and are quickly replacing the old heavy lithographic stones, one of the great advantages of aluminum being due to the possibility of its application to the rotary press, as well, also, as to its lower cost.

Aluminum hair pins are being made by the million, thus disposing of a goodly weight of wire. These hair pins give excellent satisfaction, and have been well received by the trade, who report a steady and increasing demand.

Thimbles by the thousands of gross are made by several concerns in the United States and abroad, and several tons of sheet aluminum are yearly thus employed. The metal, however, is rather soft for this purpose, as the hard steel needle soon perforates the thin aluminum shell.

For ferrules and ornamental bands, for canes and umbrellas, the metal has been successfully applied.

A large use of aluminum has developed for making metal combs, brush backs, mirror frames, and a host of toilet and fancy articles, useful as well as ornamental.

In fact, it is quite impossible to enumerate the myriad articles now being made of aluminum. One might as well make up a list of everything so far manufactured out of sheet or wire in brass, copper or nickel, tin sheets, steel and iron, and such combinations thereof, as form the materials out of which all known metal devices have thus far been manufactured, for aluminum is quietly, steadily and surely encroaching upon the domain of the metals mentioned, and with the development of its special alloys this march of conquest will proceed with ever-increasing acceleration.

The metal lends itself readily to working in the minting dies, and many very pleasing and durable effects have been obtained. Many tons of metal are yearly used in the making of coins, medals, checks, tags, religious and commemorative medallions and insignia. Artistic and permanent effects have been obtained in die work and minting by our American pressmen.

In conclusion, a few words quoted from a recent private letter to the writer, from Dr. Joseph W. Richards, who is today one of the best authorities on the subject of the aluminum industry, will be interesting.

In reviewing the wonderful growth of the industry and the success of aluminum, he says: "Is not the prospect gratifying to us who have befriended the metal, so to speak, in its infancy, have mothered it, fathered it, and even wet-nursed the struggling infant with our own substance (*i. e.*, with money out of our own pockets)?"

The brief remarks embodied in this paper and the casual facts herein set forth answer this query heartily in the affirmative.

Mining and Metallurgical Section.

Stated Meeting, held Wednesday, May 9, 1900.

MOVEMENTS OF GROUND WATER.

By Benj. Smith Lyman.

The two reports on the "Principles and Conditions of the Movements of Ground Water," by Prof. F. H. King and Prof. C. S. Slichter, in Part II of the nineteenth annual report of the U. S. Geological Survey (for 1897–98), the two issued also as a separate book of about 320 very large octavo pages, three-fifths by King and two by Slichter, might perhaps more logically have been placed in the opposite order; for Slichter, with his mathematical discussion, summarizes what had been previously ascertained, and sets forth what conclusions may, by pure reasoning, be inferred therefrom, clearing the ground, rooting out certain doubts that otherwise would constantly spring up, and firmly establishing a number of principles; while King's report is in great part taken up with the description of experimental tests and practical applications of the theories. The work of both is important, and it may be worth while to undertake here a brief, connected and easily intelligible summary of the principal valuable practical results, in the absence of what would be preferable, a summary by the authors themselves.

Almost the whole book is taken up with discussing the laws of the movement of water through the pores of the soil and rocks; for the further considerable movement through crevices in rocks or hardened soil is, of course, more irregular and in many respects less capable of reduction to precise laws. The mathematical theories and formulas are abundantly illustrated by examples and by the solution of practical problems and by diagrams.

For the purpose of at least an approximately correct idea of the movements of water through a natural soil made up of grains of various shapes and sizes, Slichter con-

siders an ideal soil of uniform spherical grains with the same "effective size" of grain as the natural ones. Such spheres, when packed in the closest manner possible, would leave about 26 per cent. of pore space, or porosity, in the whole bulk; but the most open arrangement possible with the grains in uniform contact gives a porosity of about 48 per cent. The empty spaces, or pores, for the passage of water between the spheres are, of course, not strictly capillary tubes, straight, circular and uniform in cross-section. But it is shown that the length of the axis of such a passageway is only about 6 per cent. longer than a straight line, even in the case of the closest packing of the spheres; that the triangular pore has a mean section nearly one-half larger than its minimum section, but with the flow only negligibly affected by the variations; that the flow through a circular tube is nearly three fifths greater than the flow through a triangular tube of the same area of cross-section; and, consequently, that it may be safe to reckon the pore passage as equivalent to a straight circular tube with a cross-section equal in area to the minimum triangular section of the pore.

Poiseuille, in 1842, announced his law of the flow of liquids through capillary tubes, making it proportional to the pressure and to the square of the area of the cross-section and inversely proportional to the length and to the viscosity. A brief, simple formula is therefore now deduced for the quantity of water transmitted in a second through a column of soil of a given height, area of cross-section, mean diameter of soil grains, pressure or head of water and viscosity of the water according to temperature. A very important factor in the formula depends on the porosity of the soil, making the result more than seven times greater for the most porous soils than for the least porous ones, and twice and a half greater for a porosity of 40 per cent. than for one of 30 per cent.

In the case of a sandstone bed 100 feet thick and 100 miles wide, imperviously covered above and below, and having a dip of 5 feet to the mile, a catchment area at the upper end, and a free outlet for the ground water by a

cliff or cut at the lower end, and a mean size of grain 0·15 millimeter, and a porosity of 30 per cent., the formula indicates a flow of about $\frac{9}{10}$ of a cubic foot for each linear foot of the cliff or cut, or to an artesian well 5,000 cubic feet a day; or 100 square miles of the sandstone could permanently supply only 100 wells of that capacity, leaving open crevices out of account. If the sandstone grain were 0·25 millimeter and the porosity 32 per cent., it would take but 1,500 feet linear to obtain the daily yield of 5,000 cubic feet; and with a grain of 0·5 millimeter and porosity of 32 per cent., only 400 feet linear. But from a rainfall of 36 inches a year, with, say, one-third of it entering the catchment rock, such a daily yield could not on the average be obtained from a space less than $\frac{1}{4}$ of a mile square, even though there be abundant crevices.

The formula was worked out at King's suggestion, and at his suggestion has been used inversely for calculating the "effective size" of the soil grains from the amount of the flow. He found that water did not give very uniform results, because the finer particles of sand were carried along in the current and occasioned more or less clogging or opening of the pores. But using air, with the appropriate coëfficient for its own viscosity, the results have been quite reasonably satisfactory, and much better than those of the method of counting and weighing the grains even when carefully sifted and sorted.

Slichter further shows that a problem in the steady motion of ground water in a uniform soil or rock is mathematically analogous to a problem in the steady flow of heat or electricity, or of a perfect fluid. But in stratified material the vertical motion, aside from the effect of gravity, is apt to differ from the horizontal in ease. Several problems in regard to the horizontal motion are solved and illustrated by interesting diagrams showing the circular, elliptical or hyperbolical paths of the water towards or from wells, sinks or sources, or ditches, or around dams. Then the motion of ground water in vertical planes is mathematically discussed, and it is shown that pressure appar-

ently indicated by the level of the surface of moving ground water may in certain cases be much greater than the real pressure upon the water at a given point below; for example, where the water can freely escape through a neighboring vertical plane, say the wall of a ditch or well.

Several problems of the flow of artesian wells and their mutual interference are mathematically solved. When the well fully penetrates a horizontal water-bearing bed with impervious top and bottom, a formula is obtained for the flux, assuming the bore to be large enough to carry off the water without appreciable resistance. For example, with a 6-inch well through a 100-foot horizontal water-bearing sandstone, with an effective size of grain of 0·15 millimeter and a porosity of 30 per cent. and a temperature of 50° F., when the pressure, or head of water, is 10 feet, from so much lowering the water in the well by pumping, the flux would be about 5¼ cubic feet a minute. If the effective size of grain is 0·25 millimeter and the porosity 32 per cent., the flux becomes 18 cubic feet a minute. The formula shows that the yield of a well is directly proportional to the head of water, that is, to the amount the well's water surface has been lowered by pumping, adding, of course, whatever head a flowing artesian well may have without pumping.

If the bore is large enough to carry off the water without appreciable resistance, an increase of the diameter of the well would, by the formula, increase the yield of water but slightly. For instance, if the 6-inch well that yielded 18 cubic feet a minute were increased to 12 inches, the yield would still be less than 20 feet; or if the diameter were reduced to 2 inches, the yield, aside from friction, would be nearly 16 feet. But the friction alone of a 2-inch well 200 feet deep would reduce the yield for the head of 10 feet to less than 6 cubic feet a minute. Friction would reduce the yield of a 4-inch well to about 14 cubic feet a minute, and reduce a 6-inch well to a yield of 17½ feet; but with a diameter of 12 inches the friction would not appreciably lessen the yield.

The pumping of a well and lowering its water surface

reduce the pressure of water in the rock near the well, but chiefly in the immediate neighborhood; for example, if the pressure drops 10 feet in the well, it would fall only 5 feet at the distance of about 12 feet, and then very gradually change to a fall of 1 foot at 275 feet off.

If the well do not fully pass through the water-bearing bed, the formula for the yield must be modified; and it results that the 6-inch well with the yield of 18 feet for 100 feet of depth would, if only 50 feet deep, yield from its sides 9 cubic feet a minute, and from its bottom 5 per cent. additional, or about 9½ cubic feet in all. A well 20 feet in diameter and 22 feet deep in soil of the same coarseness, porosity and temperature as that 6-inch well would yield about 22 cubic feet a minute.

A table is given for the yield of a 6-inch well sunk through a bed 100 feet thick of material of various degrees of coarseness and with various heads of pressure, with porosity 32 per cent., and temperature 50° F.; showing for 0·02-millimeter grains and 4 feet of head a yield of less than five-hundredths of a cubic foot a minute; but for 3-millimeter grains and 20 feet of head a yield of 5,322 cubic feet a minute, leaving well friction out of account.

It is shown with a large illustration how to draw the curved lines of flow into a well in a region where the ground water has a constant motion in a general direction. The mutual interference of two wells is mathematically discussed; and is illustrated with diagrams of the lines of flow, both for wells yielding equally and for one yielding twice as much as the other.

Suppose the water of two wells 10 feet apart to be lowered in each 10 feet by pumping, each well will yield about 34½ per cent. less, owing to the interference; at 100 feet apart, about 20 per cent. less; at 200 feet apart, about 15 per cent. less; at 400 feet apart, about 10 per cent. less; at 1,000 feet apart, about 6 per cent. less. In like manner the interference of three 6-inch wells in a row 5 feet apart would be 55 per cent.; 10 feet apart, about 51 per cent.; and 100 feet apart, about 31 per cent. In other words, two wells 10 feet apart would yield 131 per cent. as much as a single

well; and a third well half way between them would make the total yield only 135 per cent. of the flow of a single well. But if the two wells are 200 feet apart they would together yield 169 per cent. of the flow of a single well; and a third well midway between them would bring the total up to 207 per cent. of the flow of a single well.

From the bottom of the above-mentioned 20-foot well, 22 feet deep, yielding about 22 cubic feet a minute, suppose one, two or three 6-inch wells to be sunk 200 feet into the sandstone. As already seen, one such 6 inch well would yield about 18 cubic feet for a depth of 100 feet, or about 36 cubic feet for a depth of 200 feet, enough, then, to increase the total yield to about 58 cubic feet; but, as the pressure varies inversely as the square of the distance from the large part of the well, making the upper 20 feet or so of the 6 inch well useless or yielding chiefly at the expense of the large well, the total yield would probably be only 54½ cubic feet. Two such 6-inch wells 5 feet apart would in like manner increase the total yield to about 62 cubic feet a minute; or if 10 feet apart, to 64½ cubic feet. Three such 6-inch wells 5 feet apart in a line would bring the total yield up to about 66 cubic feet a minute; but if 10 feet apart, to 71½ cubic feet.

The mutual interference of a large number of wells in a row is also investigated mathematically, and a small table of results is given for 6-inch wells that have had the water surface in each lowered 10 feet by pumping: If 100 feet apart, the interference is nearly 66 per cent.; if 200 feet, 45 per cent.; if 400 feet, 24 per cent.; if 600 feet, 14 per cent.; if 1,000 feet, about 6½ per cent.

The report ends with a bibliography of about eighty important works bearing on the subject.

So much for Slichter's mathematical theories, very valuable and yielding interesting and even surprising results; yet necessarily based on conditions more uniform than can scarcely be found in nature, and so, of course, not to be taken too strictly in application to natural cases.

Now for King's practical observations. He gives 100 pages to a discussion of hundreds of his ingenious and

painstaking experiments with water, with air and sometimes with kerosene passed through sand, sandstone, dust shot, gauze, bundles of knitting needles and capillary tubes, and to a review of the experiences of others, to test the accuracy of Poiseuille's law that the flow is proportional to pressure, the law that was taken as the very foundation of much of the mathematical work. Further on he gives some 300 experiments of his own on the flow of water in a given time through ten grades of quartz sand of different coarseness, illustrated with natural-size pictures of scattered grains not closely packed. The result of the whole is that the flow is often not proportional to the pressure, generally increasing faster than the pressure, sometimes slower, in every case systematically faster or slower; not sometimes one way, sometimes the other, as if from errors of observation. The flow of water has increased faster than the pressure in some trials with sand by nearly 46 per cent.; with rock by nearly 86 per cent.; and with capillary tubes by nearly 21 per cent. The general result in the graded quartz sand experiments was that with the finer grains and low pressures the flow increased faster than the pressure; but with coarser grains the flow increased more slowly than the pressure, because of turbulence in the larger pores. Indeed, the already-known fact of sometimes slower flow had formerly been accounted for by the absorption of energy at the ends or within the body of the tube containing the sample tested. But it is not so easy to understand King's faster increase of flow than of pressure if the viscosity of water and air is really independent of pressure, as inferred by Maxwell. King suggests that the stationary or slowly-moving film of liquid adherent to the walls of the capillary passage may, under high pressure and greater velocity, become thinner, or, in part at least, may be accelerated more rapidly than the pressure increases; so as in effect to increase the diameter of the passage.

He gives the results of 150 conveniently expeditious tests of sands and soils with his fully described aspirator or apparatus for determining the effective size of grain by drawing air through them, and tabulates the results along with

the observed pore space and the rate of movement of the air. The pore space is determined by computation from the weight and specific gravity of the amount required to fill a cylinder of known capacity with the closest packing; that is, with gradual filling and frequent gentle tamping and with gentle jarring at the close. He finds that both the upper and lower theoretical limits of pore space for the ideal soil, about 26 and 48 per cent., as above mentioned, are but slightly exceeded, and that the porosity in all cases lies between 25½ and 53 per cent. The fine-grained elements tend to give a larger pore space than the coarser ones. The smallest pore space results from mixing grains of different size. The simple sands, with well-rounded grains about 0·15 millimeter in diameter, lie close to the mean value.

It is seen, then, that the amount of water stored in saturated soil—that is, below the ground water surface—is, in round numbers, two-fifths of the whole bulk. Usually three-quarters as much is to be found even in soil above the plane of saturation, except during dry times in a surface layer 1 to 5 feet thick. Saturated sandstone may contain as much as 38 per cent. in bulk of water, equivalent to immense and deep lakes in certain widespread level-lying Western sandstones. Even compact marbles and granites contain an appreciable percentage of water. It is probable that water penetrates the earth's crust in some degree to a depth of more than 10,000 feet.

But consolidated and deep-lying rocks have, in growing compact, lost much water. Fine silt deposited in water contains more than half its bulk of water, but, on compression by overlying sediment, part of the water is driven out, either upward, downward or sidewise. Evidently, vast quantities of water must so have been expelled from the enormous masses of rock that now underlie, for example, the Appalachian region, much of the rock at present having less than 1 per cent. of pore space. Furthermore, such water-bearing sediments, when carried down several thousand feet, must in higher temperature expand and drive out water in some direction, the water flowing much the more readily from its lessened viscosity at a higher temperature.

Moreover, the gradual deposition of mineral matter from the stationary film of water around the grains of a sandstone, and the consequent absorption of other mineral matter by the film from neighboring circulating water, and again the deposition of this absorbed material, until the rock becomes much more compact and less porous, must occasion the expulsion of great quantities of water in the case of vast bodies of rock. The consolidation of 50,000 square miles of sediment 1,000 feet deep, with an original pore space of 33 per cent. reduced to 3 per cent., must require the expulsion of a sheet of water 50,000 square miles in area and 300 feet deep, and its replacement by solid rock material—enough material to take the Mississippi River 60,000 years to supply, even with 150,000,000 tons carried in solution annually to the sea, according to T. M. Read's high estimate. Of course, such subterranean movements of the water must be extremely gradual and last through immensely long periods of time.

Some computations of the rate of flow of more superficial waters under definite conditions are given, and thereafter a comparison with results actually observed on a large scale in nature. For these computations the rate of flow is taken to be, according to Poiseuille's law, proportional to the pressure and inversely proportional to the length of the sand column; and proportional to the square of the diameter of the grains, in this respect nearly in agreement, too, with the 300 experiments on the ten grades of quartz sand. The computations show that at the drainage outlet of a bed of sand fully supplied with water and 10 feet thick, rising 1 foot in 10, the slope or gradient just compensating for the loss due to increase of length traversed by the water, a square foot of outlet surface would yield for the coarsest ($2\frac{1}{2}$ millimeters) sand about $5\frac{1}{4}$ cubic feet a minute; but for fine sand only a quarter of one ten-thousandth of a cubic foot, or, compared with the result for the coarsest sand, as one minute to 138 days; and for fine sandstone less than a hundred-thousandth of a cubic foot; showing that the rate of flow varies between very wide limits. In like manner the rate of flow is calculated for several supposed sands, and

with dips also of 1 in 1,000 and 1 in 2,000; and it is found that the results are far less than the yield actually found by Darton under comparable circumstances in the Dakota artesian basin. It is, therefore, clear that ground water in moving long distances must flow not merely through the pores, but in great part through joints and fissures, perhaps even through such passages in beds adjoining the water-bearing bed proper. Similar calculation of the theoretical rate of seepage into a portion of the Los Angeles River, into the flume of the West Los Angeles Water Company, and into the pipes of the Crystal Springs Land and Water Company, shows in each case results so much less than the ones really observed as to make it evident that the actual supplies of water must be accounted for otherwise than by mere seepage through capillary pores, and probably by larger submerged open waterways, even in the case of loose river sands. In the soil the passage of water is facilitated by worm burrows and the holes left by decayed rootlets.

In one experiment 200 cubic feet of water was forced in four days into a 7-inch well 13½ feet deep in undisturbed soil, where the ground water surface was 11⅔ feet below the top of the ground. The well was curbed with 5-inch unglazed drain tiles in 1-foot lengths. The water surface in the well was maintained at 7 inches below the top of the ground. Though the ground water surface was made to rise steeply within 2½ feet of the well, that surface at 4 feet from the well was raised only about 3 inches, showing that much of the 200 cubic feet of water must have spread away in all directions to quite long distances.

Experiments were made with a tank 14½ feet long by 4 feet deep and 1 foot wide, filled with mixed sand, and having a vertical drain tile inside one end to supply water, and four cross tiles at different points to drain off the water with cocks outside, and having fifteen pressure gauges uniformly distributed along one side. The water was discharged by one cock or another, and the pressure at the bottom of the tank at different distances from the outlet was noted, and was plotted in curves upon an elevation-drawing of the apparatus. The curves descend very gradually at the supply

end, and much more rapidly near the outlet. This illustrates what is observed on a large scale in nature.

For, contrary to widespread belief, the ground water surface near streams and lakes is higher than their water, and the movement is towards them, not from them. The contour of the ground water surface, as tested by numerous wells and shown in map illustrations, is found to conform somewhat to the shape of the surface of the ground, but deeper below it at higher points than in the valleys and with variations due to such circumstances as the varying porosity of the soil or the drainage of neighboring streams, wells, or tile drains. The ground water surface is far from level, and at one point has a gradient of 5 per cent. towards a lake only 150 feet distant; and at another point a gradient of 6 per cent. Plainly, then, streams, small lakes and low grounds receive throughout their course much, in fact, nearly all, of their water from adjacent higher land.

The amount of water, then, that has passed through the soil is enormous, as may be seen from estimates of the run-off. Newell has pointed out that the run-off in the region east of the Mississippi, except towards the northwestern corner, is about half the rainfall; in the region next west to the western edge of Missouri, it is about two-fifths of the rainfall; and in a narrow strip to the west of that, about three-tenths; and in a region still further west to the eastern part of Montana, it is from one-fifth to one-quarter. In the more level part of the United States, therefore, one-fifth to one-half of the rainfall goes into the streams; but, as we have seen, far the larger portion of that run-off has once penetrated the soil and emerged again before it reaches the river channels.

The tank afterwards had three more sets of gauges added, making sixty in all, and the water was drawn off by a cock near the middle of the bottom of the tank, while the sand was kept full of water to the surface. The pressures indicated by the gauges are shown in curves plotted upon a drawing, agreeing with Slichter's indication of the great decrease of pressure near a drainage outlet, even when the ground water surface remains undisturbed. But King con-

siders it very rare for such conditions to exist as to make that type of well interference at all marked, and that the serious cases of well interference come from an actual lowering of the ground water surface.

It was found by a trial of the interference of two wells 1,133 feet apart that pumping one did really change sensibly the level of the water in the other. This fact may appreciably affect some of the mathematical formulas; for in them the distance of 600 feet was taken to be the limit of such change to the ground water surface.

With the same tank experiments were also made that show the effect of adding a small quantity of water, corresponding in nature to the percolation of rainfall, to be very great in raising the ground water surface; because the empty space in the zone of soil nearly saturated by capillary attraction just above the level of the ground water surface is very small indeed, as appears also from King's experiments with five columns 8 feet long of sand of different coarseness left to dry even two years and a half. In all the five sands the lower foot was left very moist, and, in the two coarser ones, the next foot upwards was much drier, and above that there was little change; while the other sands were more uniformly drier from the bottom foot towards the top of the ground. The result is that a very small rainfall $\frac{1}{4}$ or $\frac{1}{8}$ of an inch in any of the sands would suffice to raise the ground water surface a foot; about 5 inches and less than 13, according to the coarseness, to raise it 4 feet. Of course, for short periods of drying, say a few days, the amount of rain required for the same results would be much less. As the ground water surface rises, then, more rapidly in soils of close texture, they would, with greater head, drain out more rapidly and contribute a large share to the swelling of the streams. Furthermore, observation shows that the ground water of low-lying land, from nearness to the surface, may, by rain, be raised to the highest level and begin to fall again before the rain water can percolate to the bottom of the deeper partially dried soil of the higher land.

Movement by capillary attraction takes place in all directions that lead from water-filled pore spaces of the soil to

others that are empty or only partly filled; and is quite rapid to a height of 4 feet, but its limit of height is not known. Its most general effect is to lessen the ground water by bringing it to the surface of the soil or to the roots of plants, and so to evaporation. The coarser the soil, the less the capillary attraction movement. The five columns 8 feet long of sand of different coarseness, after evaporation for two years and a half, still retained from 4¼ per cent. of water in the coarsest to nearly 12 per cent. in the finest. The water left was chiefly near the bottom of the column, where it varied only from 21½ to 24 per cent. Other experiments showed that evaporation was very much the most rapid when the ground water surface was less than 18 inches from the surface of the ground, and greatly lessened with an increase of depth. Clearly, then, where the ground water surface is more than 8 feet deep, nearly the whole rainfall must descend at once too far for capillarity to bring it again to the surface. The percolation of the rainfall is hastened by worm burrows, holes left by decayed roots and by shrinkage cracks. It is hindered by the air that has filled the empty pore spaces, and that escapes with especial difficulty from the finer soils.

The natural movement of water in the ground is affected by barometric changes of the weather; and a lessened barometric pressure causes a more rapid discharge of water from springs, flowing wells, tile drains and seepage outlets of all kinds. The reason is not yet perfectly certain; but King suggests that it may be either because the general level of the ground water surface is bodily lowered or raised, just as in the case of portions of the surface of the open ocean, by the greater or less pressure of the atmosphere upon it; or because the partially confined air in the soil may drive out the water more or less strongly according to the lessened or increased resistance of the atmospheric pressure. (Is it not rather that the column of water, more or less perfectly closed above by the soil, somewhat difficultly permeated by the air, as just intimated, thereby practically resembles a barometer tube, and a lessening of atmospheric pressure upon the open drainage outlet allows

the water to issue more rapidly by its own weight?) Diurnal changes of temperature also hasten or retard the flow of water through the soil, not so much by changing the viscosity of the water as by the expansion or contraction of the gas confined in the soil with and above the water.

Serious and very costly mistakes in well digging are made from ignorance of the laws of the movement of ground water. The City Water Works Company, of Whitewater, Wis., was just about to ask for bids for a second well, for $1,200 or $1,500, when King suggested lowering the level of discharge of the first well, so as to increase the head of water pressing into the well. Thereby the capacity of the well was more than doubled, for it is to be borne in mind that the yield is directly proportional to the amount the water is lowered in the well, that is, to the head or pressure. A well at the dairy building of the University of Wisconsin was stopped on reaching a loose sand, and a building was erected above; so that the well could not be deepened without great expense, when it was found a large water supply was needed, such as could have been obtained by sinking deeper at first for an outlay of $60.

The flow, however, as shown by Slichter's calculations, does not increase exactly in proportion to the depth of penetration into the water-bearing bed; for the shallower wells have a larger supply from their bottom. But his calculations show that an increased depth of the water-bearing bed below the bottom of the well increases the yield only a little for the first few feet, and beyond that very slightly, and in all only $\frac{1}{8}$ up to a depth of 100 feet, and for greater depths insignificantly, and beyond 400 feet not at all. Besides, the beds are never perfectly homogeneous, and particularly not so vertically, and the water generally flows more readily along the bedding planes than across them. The flow towards a well, too, will be out of the finer grained layers into the coarser ones, in which, also, the reduction of pressure is greater and farther reaching. In casing a well, then, care must be taken not to let the end of the pipe stop in a fine-grained layer. The flow from the

finer grained beds with higher pressure and higher speed, or from local crevices, into the coarser beds is liable to carry along small particles of sediment that tend to settle in the slower moving streams of the coarser beds and clog their pore space and by degrees appreciably reduce the yield of the well.

The public is certainly much indebted to the authors and to the Survey for so thorough, careful and practically useful a discussion of the laws of the movements of ground water, applicable also in great measure to rock oil.

PHILADELPHIA, May 8, 1900.

CHEMICAL SECTION.

Stated Meeting, held Tuesday, November 21, 1899.

THE INFLUENCE OF SCIENCE IN MODERN BEER BREWING.

BY FRANCIS WYATT, PH.D.,
Member of the Institute.

(*Concluded from p. 214.*)

In order to prepare zymase, brewers' yeast is carefully mixed with an equal weight of quartz sand and infusorial earth, and rubbed down until the mass is soft and plastic. Water is added to this paste and the whole is placed in a pressing cloth and gradually subjected to a pressure of 400 to 500 atmospheres. The residual mass is again rubbed down, moistened with water, replaced in the pressing cloth, and subjected to the same pressure as before. In order to remove traces of turbidity, the total expressed fluid is mixed with a small quantity of infusorial earth and, after pouring over the first portion several times, is finally filtered through a paper filter. It now appears as a clear but opalescent yellow fluid with a pleasant odor of yeast. Its minimum specific gravity should be 1·0416. When boiled, there is a marked separation of coagulum, so that

the fluid almost stiffens. The formation of insoluble coagulum commences at about 95° F., preceded by the escape of the carbonic acid gas, with which the fluid is saturated. The extract should yield upwards of 10 per cent. of dry substance, and it should have the faculty of causing fermentation in saccharine solutions.

The investigations and discoveries of Buchner have proved the correctness of Liebig's suspicion, and justified the painstaking—if unsuccessful—labors of Traube, Claude-Bernard, Berthelot and many other equally prominent investigators who have believed in other than mere hydrolyzing enzymes like diastase. Now that zymase has really been found and isolated, however, it is a question whether we can make any practical use of it in the fermentation of beer, or whether it is to be regarded in the light of an interesting scientific discovery only.

I cannot, of course, presume off-hand to answer this question one way or the other; but, as I now see the matter, it would appear that the sole method of producing zymase is by extracting it from yeast by some modification or simplification of the process I have just outlined. I am, therefore, led to ask, whence are we to get the needed supply of yeast for its extraction, and what would be the compensating advantages which our brewers would derive from its use? We must not forget that yeast performs many functions in our worts during the course of fermentation besides the mere production of alcohol and carbonic acid gas. It removes certain objectionable bodies of the albuminous and resinous types, and thereby facilitates clarification and insures stability. Can these functions be performed by zymase? Then again, the production of yeast in a brewery is a matter involving great care and great cleanliness and great delicacy of treatment, but it is produced for comparatively nothing. If zymase can be obtained only from yeast, whence is the brewer to get his supplies and what is it going to cost him? What are its keeping qualities? How is it affected by the temperatures at which fermentations are conducted in this country? These are important questions, and there are a number of others of still greater importance

which will occur to those who give this interesting work of Buchner's the consideration it deserves.

Buchner demolished the pet theory of the majority of scientists by proving that the production of alcohol and carbonic acid gas from the fermentation of sugar is not the result of "life without air." Some of these days we may find out how this discovery is going to help us to make better beer.

The species of wild yeast most commonly found contaminating our beer worts are the *Saccharomyces pastorianus*, *Saccharomyces ellipsoideus*, *Saccharomyces exiguus* and *Saccharomyces apiculatus*. All these are present in the atmosphere as well as on the surface of all fruits and seeds, so that if a brewer's wort is freely exposed to the air, it will, in the course of a few hours, develop a spontaneous fermentation. These various species of wild yeast will be accompanied by various species of bacteria and moulds, which will rapidly grow and multiply, and in a few days—if left to itself—the wort becomes covered with a thin film, emits a disagreeable smell, and soon putrefies.

The species of bacteria or disease germs commonly met with in breweries are:

The *Bacillus subtilis*, *Bacillus amylobacter*, *Bacterium termo*, *Bacterium aceti*, *Bacterium lactis* and *sarcina*, and of these, we know that the *Bacterium aceti* has the power of converting the alcohol of the beer into acetic acid or vinegar; the *Bacterium lactis* attacks the saccharine matter, converting it into lactic acid, whilst butyric acid is derived from the further fermentation of the lactic acid by means of the Bacillus amylobacter.

The two well-known kinds of fermentation used in this country are known as "top" and "bottom." Top fermentation produces ale, and is carried on at temperatures between 55° and 75° F. The yeast is conveyed to the surface, and the fermentations generally last from four to seven days. Bottom fermentation produces lager beer, and lasts from nine to fourteen days. It takes place at temperatures between 2° R. and 9° R. The yeast, by reason of the sluggish nature of the fermentation and its heavier specific

gravity, subsides completely to the bottom of the fermenting vessel, although during the earlier stages the head exhibits the same appearance as the top fermentation.

Having thus dealt with the materials used in the modern brewery, I will now give a brief descriptive outline of the modern brewing plant, which is nearly always so arranged that everything may run by gravity, thus avoiding unnecessary pumping.

(1) Hot and cold water tanks, with all necessary connections.

(2) The "Raw Grain Masher" or decoction tub, which is a large, round, iron vessel, provided with a jacket, for either steam or cold water, and with an inside connection for introducing live steam into the mash. Its internal rakes are adjusted so as to sweep as closely as possible the sides and bottom, and it has a sparger for hot or cold water, the necessary steam and water gauges, and thermometers being affixed externally. It is generally large enough for the treatment of 300 bushels of grist, and it always commands the malt mash-tub from an elevation of about 6 feet, being connected with it by a 6-inch pipe.

(3) The "Malt Mash-Tub" is a vessel built of sheet steel and provided with a copper false bottom. It has strong revolving rakes, and a scraper which may be lowered to within $\frac{1}{8}$ inch of the bottom or entirely raised from the mash by means of a hydraulic hand pump.

(4) A steam-jacketed copper boiling kettle, in which the whole of the worts collected from the mash-tub are boiled with the hops.

(5) A hop-jack to receive the finished worts when they run from the kettle.

(6) Several good pumps for wort, beer or water.

(7) A sheet-iron open surface cooler, provided with a fine spraying apparatus, through which the wort is pumped from the hop-jack.

(8) A Baudelot refrigerator, the upper coils of which are cooled with cold water, and the lower ones with cold brine or by direct expansion of ammonia.

(9) An ice machine and all accessories for the production

of cold. Imagine a compressor driven by a steam engine. This compressor receives ammonia in the form of vapor from the other end of the system and compresses it, heating it, of course, at the same time. The compressed ammonia passes into a condenser, or coil of pipes, on the outside of which trickles a stream of cold water, which carries off the heat from the ammonia and thus causes it to liquefy. The liquid ammonia goes into a separator and settles to the bottom. The opening of a certain valve of special construction allows this liquid ammonia to expand and escape into coils of pipe. In the act of expansion it absorbs heat and the surroundings are thus cooled. Having reassumed the form of vapor, it is now led back to the compressor and again liquefied.

(10) Boilers, engines, elevators, malt bins, malt screens, malt mills, and scales. A cold storage room for the hops, well insulated, is connected with the refrigerating machine.

(11) Well-insulated and cooled fermenting rooms and cold storage rooms, all so arranged by connection with the refrigerating plant as to facilitate the maintenance of any desired temperature, from the freezing point up to 55° or 60° F.

(12) Fermenting tubs, storage casks, and finishing or pressure casks, all varnished on the inside with the best insoluble, hard, elastic shellac varnish; filters, racking apparatus and trade barrels of all the various capacities to meet requirements.

It is perhaps hardly necessary for me to tell you that science has impressed upon the modern brewer the condition *sine qua non* of absolute cleanliness as the principal factor in the production of good beer. Let him neglect this condition and he can no more make good beer than water can run up hill. Before commencing his work, therefore, he will always see to it that his plant is perfectly clean; that the false bottom of his mash-tub is properly adjusted, and that none of the holes are clogged up. He will also see that the raking gear moves with perfect freedom and ease; and that it is adjusted to any necessary speed to make a mash of proper consistency. He will test the thermometers,

and see that they record correct temperatures, and will try all the valves and taps.

Proceeding by progressive steps, he has also been brought to realize that next in importance to cleanliness comes the question of the different temperatures which are to be observed throughout the various phases of his brewing process, and, as this is the very *crux* of my present exposition, I will try to make it more clear to you by a glance at what actually should take place when the malt is mixed in the mash-tub with the water at correct temperatures.

(1) The pre-formed sugars of the malt, together with the soluble albuminoids or nitrogenous bodies and the mineral salts, go into solution.

(2) The starch of the malt is gelatinized by the hot water.

(3) The diastase acts upon the starch in strict accordance with the temperatures to which it is exposed.

You will perceive from this that the conversion products may be varied at will, and the production of any desired type of beer be positively assured.

If, for example, we employ low temperatures for the preliminary digestion of the malt in order to accomplish Phase No. 1, and then raise the temperature either by means of steam or additional hot water to, say, 148° F. to accomplish Phases 2 and 3, we know that we shall be effecting our conversion under the optimum conditions favorable to the action of the diastase. Our worts will, therefore, contain a large proportion of free and directly fermentable maltose sugar, which, by fermentation, will produce a very alcoholic, or, as it is technically termed, a very vinous beer.

If, on the other hand, we rise rapidly from the low temperature of digestion to 154° or 156° F. in order to accomplish Phases 2 and 3, we shall so restrict the action of the diastase, so cripple it, in fact, that our worts will contain a comparatively small proportion of free maltose and a correspondingly large proportion of malto-dextrine and dextrine; and our fermented beer will have comparatively little alcohol and much "body" or residual unfermented extract.

Thus, you see, science has found out and demonstrated

that the type of beer desired may always be obtained by a proper regulation of temperatures, and I shall endeavor to give you an example of this by a brief description of the brewing process proper, conducted in accordance with modern views. Let us suppose that we require 200 barrels of a beer of vinous character. We establish the initial temperature of the mixture of malt and water at 137° F., in order to thoroughly digest the grain and dissolve out all the diastase and other soluble nitrogenous bodies. We next accomplish Phase 2 and Phase 3 of the process at 148° F., in order to facilitate the action of the diastase and to thereby produce a ratio of fermentable to non-fermentable matter in the wort which shall be in the neighborhood of 1 : 0·37. We finally raise the temperature of the mash to 155° F. to prevent undue cooling off and the consequent formation of excessive acidity.

We wash out or exhaust our grains with water at 160° F. in order to maintain the temperature of the mash at about 154° F. throughout the operation, despite losses by radiation.

The water is run into the mash-tub in the proportion of 1·75 to 1 (by weight) of the grist, and at a temperature of 154° F. The mashing machinery is now started to revolve at moderate speed; the malt hopper is opened and 327 bushels of malt are run down into the water at the rate of 100 bushels in five minutes. When it is all down the mashing is continued for five minutes, and then the rakes are stopped and the mash rests for thirty minutes. At the end of this time sixteen barrels of boiling water from the hot-water tank are let into the mash as rapidly as possible from underneath.

This will give a temperature of 148° F., at which the gelatinization and actual conversion of the starch take place, and by which the type of the wort is established. After being maintained with constant mashing for twenty minutes, this temperature is increased to 155° F., for the purpose of keeping up the heat while the mash rests, or settles to form a filter bed over the false bottom of the tub.

When the mash has rested one hour the taps of the tub are opened full and allowed to run for about one-half

minute at their full capacity, in order to clear out the pipes. They are then adjusted so as to deliver about sixty or seventy barrels of liquid per hour.

When about ten barrels have run off into the wort kettle, the liquid running from the taps should have a temperature of about 153° F.

When thirty barrels of wort are in the kettle, the sparger on top of the mash-tub is opened, and twenty barrels of water are sprinkled over the grains. Thenceforward for every twenty barrels that run off from the mash-tub twenty barrels are put on top of the grains through the sprinkler until the soluble matter contained in them is entirely washed out.

Speaking in a general way, it is found that the required amount of total water to be used is in the proportion of 6 to 1 of grist. In the present illustration, therefore, since we intend to produce 200 barrels of wort in the fermenting tubs, we should have:

$$\text{Grist, } 11{,}128 \times \frac{6{\cdot}4}{259} = 275 \text{ barrels.}$$

Water used for first mash	75 barrels.
Water used in second mash, underneath, boiling	16 "
Water used in third mash, " "	14 "
	105 "

Water available for washing out the grains, 170 barrels.

The specific gravity of the last runnings into the kettle from the mash-tub in good practice is generally about 1·005.

The total quantity of wort run off into the kettle from the mash-tub is about 16 per cent. less than the total quantity of water used in the brew; the balance being mechanically absorbed by the grains.

The wort in the kettle is kept near to the boiling point, but not allowed to quite boil, until it is all collected, when it is boiled very steadily for two and one-half hours.

The hops are added as follows:

One-third when the kettle has been boiling thirty minutes.

One-third when the kettle has been boiling one and one-half hours.

One-third about twenty minutes before "turning out."

The quantity of wort discharged from the kettle at the boiling point is about 210 barrels, or in other words, is about 5 per cent. greater than what is required in the fermenting cellar at the necessary cold temperature.

If the wort produced in this manner is subjected to analysis, it will be found to exhibit the following average composition:

Specific gravity at 60° F.	1·053
Total solid extract (by weight), per cent.	13·37
Fermentable sugars in extract (estimated by Fehling's solution as maltose)	9·75
Proteids or nitrogenous matters (suitable as yeast food)	0·74
Total acidity (estimated as lactic acid)	0·14
Ratio of fermentable matter to the other bodies in the extract not fermentable	1:0·37
Ash (phosphates, etc.)	0·22

I will only pause to draw special attention to the amount of fermentable sugars in the wort, and the ratio in which they stand to the non-fermentable bodies, in order that you may form intelligent conclusions later on; and with your permission will now pass on to a consideration of another mashing operation, in order that its results may furnish material for proper comparison.

In the present instance we shall proceed with the mashing process on exactly similar lines, so far as the mechanical arrangements are concerned, but we shall replace a certain proportion of our malt by a certain quantity of raw grain. For the sake of brevity, let me tabulate the brew like this:

Quantity of wort required in fermenters	200 barrels.
Gravity of wort in fermenters, when cold	1·053
Ratio of fermentables to non-fermentables	1:0·51
Conversion temperature is to be	158° F.
Proportion of total water to grist is	6¼ to 1
The water for the malt mash is at	120° F.
Proportion of water to malt for the malt mash is	2·50 to 1
The raw grain mash is to be boiled	212° F.
The raw grain is mixed with 50 per cent. of its weight of malt.	
The proportion of water to the total grist in the raw grain mash is	2·50 to 1
Temperature of the water in the hot-water tank, to be used in the underflow of the mash-tub to bring up the tem-	

perature of the entire mash to the desired point at which it is to rest, is . . . . . 212° F.
The final resting temperature of the mash . . . . . 164° F.
The total amount of sparge water is of the total water to be used . . . . . 58 per cent.
The temperature of the sparge water is . . . . . 166° F.
The tap heat throughout the run is . . . . . 158° F.

The hops used in the brew are in the same proportion as for the one preceding, and are used in the same manner.

In the first example we used 327 bushels of malt; in the present one we shall use:

213 bushels malt; 3,322 pounds corn grits (equal to 114 bushels malt); 276 barrels water.

The raw grain mash is made thus:

Corn grits	3,322 pounds.
Malt	1,661 "
Total	4,983 "

$$4{,}983 \times \frac{2{\cdot}50}{259} = \text{say, 49 barrels of water.}$$

The forty-nine barrels of water are in the raw grain tub or converter at a temperature of 130° F. The rakes are started and the malt is put in first; then follows the corn; then the steam is turned on, and the temperature is raised 1° F. per minute until it boils. Boiling is continued for one hour, and the boiling mass is then run into the malt mash-tub below. When the converter is empty, it is washed out with seven barrels of water. Allowing five barrels for evaporation, this makes a total of fifty-one barrels of water in the raw grain mash.

The mashing of the malt is done thus:

Malt, 5,572 pounds.

$$5{,}572 \times \frac{2{\cdot}50}{259} = 54 \text{ barrels of water.}$$

The fifty-four barrels of water are in the mash-tub at 120° F. The rakes are set in motion when the corn mash has been boiling for thirty minutes, and the malt is let down at moderate speed and mashed slowly. As soon as the raw grain is ready, the two mashes are brought together

as quickly as possible, and kept in motion for thirty minutes, the temperature being as follows:

Foundation temperature of malt mash water	120° F.
Initial temperature of malt and water mixed	109° F.
Conversion temperature of the combined raw grain and malt mashes	158° F.

At the end of the thirty minutes the temperature of the mash is raised to 164° F. by means of fifteen barrels of boiling water, which are let in through the false bottom as quickly as possible. The rakes of the mash machine are stopped and the mash is allowed to rest for one hour in the usual way.

I need not again describe the balance of the operations of running off the wort and sparging, because they are conducted exactly as in my first example; the quantity of sparge water is the balance between the total water required for the brewing, calculated at 6¾ to 1, by weight, of the total grist, and the water already used as I have set forth.

If, after boiling, hopping and cooling this wort, we subject it, like the other, to chemical analysis, we shall find that its composition is as follows:

Specific gravity at 60° F.	1·053
Total solid extract (per cent.)	13·37
Fermentable sugar in extract (estimated by Fehling's solution as maltose)	8·80
Proteids or nitrogenous matters (suitable as yeast food)	0·53
Total acidity (estimated as lactic acid)	0·12
Ratio of fermentable matter to the other bodies in extract not fermentable	1 : 0·52
Ash (phosphates, etc.)	0·19

I do not think you can fail to at once perceive the difference in the amount of fermentable sugar, and the ratio in which it stands to the non-fermentable bodies, as compared with the wort from our first brew, but in any event I again impress it upon your attention for future reference.

The wort that has been boiled in the kettle as I have described has to be cooled and mixed with the yeast. To this end, the valve of the discharging pipe of the kettle is opened wide and the boiling wort is allowed to run by

gravity into the hop-jack. This hop-jack is provided with good false bottom plates to retain the hops, which form a filter bed for the wort, and prevent the passage of coagulated albuminoids and any other suspended matter. When the wort has settled in the hop-jack for thirty minutes the outlet valve is opened and the wort is pumped to the surface cooler or collecting tank, situated at the top of the brewery.

The chief objects to be effected at this stage of the operations are two in number:

(1) That of cooling; and

(2) That of oxidation.

In order that this all-important oxidation may effectually take place, it is necessary that the wort should be at a temperature very little below the boiling point. In about thirty minutes from the time it leaves the hop-jack the wort is conducted over coils of refrigerating pipes, the upper ones being cooled with cold water, and the lower ones either with cold brine or with ammonia directly expanded from the ice machine. The temperature of the flowing wort is continuously recorded in the pan of the refrigerator, which is sufficiently deep to allow a considerable quantity to accumulate, and must be carefully maintained at the desired point.

No chemical change takes place in the wort while it is passing over the refrigerator, but it absorbs a certain amount of free oxygen mechanically, which the yeast uses up before commencing its attack upon the sugars. The mixture of the yeast takes place in the starting tub as soon as the wort has reached the proper temperature.

The fermentation, storage and finishing of the beers take place either in vast cellars underneath the brewing rooms or in a cold storage house immediately adjoining them. In the best modern establishments the fermenting room is situated at the top of the building, and the beers run through the various subsequent processes by natural gravity. Each department is well ventilated, the floors are paved with cement or asphalt, and the walls and ceilings are cemented and enamelled and kept perfectly dry. The

cooling pipes connected with the ice machine are suspended from the ceiling or hung upon the side walls, well removed from the open fermenting tuns, and every precaution is taken to prevent any drips from falling into and contaminating the beers. The drains are well trapped and of large capacity, and plenty of use is made of cold water for flushing the floors, and of such disinfectants as chloride of lime, sulphate of iron, etc. The temperature of the fermenting room is kept at 40° to 42° F. The fermenting tuns are round vessels, built of oak; fitted with attemperators; varnished inside; capable of holding from 50 to 100 barrels, and provided with a manhole to facilitate proper cleaning and the withdrawal of the yeast. In a few breweries which are completely under the direction of trained scientists the beers are fermented with pure yeast, successfully cultivated from a single selected cell on the Hansen plan. In the majority of cases, however, it is still customary to constantly use the same stock, collected from the fermenting tubs. The yeast crop secured is generally three or four to one, and directly it is taken out it is washed with boiled cold water to free it from dirt and light yeast, allowed to settle, placed in a very clean tub, covered with boiled cold water, and stored away in the coldest possible condition. Beer enters upon its initial stage of fermentation in twenty-four to thirty-six hours from the time of adding the yeast, and its temperature will now rise at the approximate rate of a degree Fahrenheit every twelve hours. It usually reaches a maximum of 51° F. to 52° F., and the top, or cap—until then kept up by the evolution of carbonic acid gas—commences to fall back, and is skimmed off. The attemperating coils in the fermenting tuns are now put to work very carefully, and the temperature is reduced to 37° F. at the rate of about $\frac{3}{4}$° F. per twelve hours. The specific gravity of the beer is now about 1·015, and if it preserves this without change for twenty-four hours, and presents, after final skimming, a perfectly black appearance when regarded from above, its fermentation is at an end and it is ready to be sent off into the storage cellar.

The temperature of the storage cellar is kept as uni-

formly as possible at about 35° or 36° F., the storage casks being of oak, painted inside with a good coating of pitch, and of about 400 barrels capacity. In order that the quality, odor and flavor of the beers may be homogeneous and their specific gravity more regular, different brewings are distributed and mixed together throughout a series of casks, which are all fitted with porous bungs. No fermentation should take place in the storage room, but the beers must deposit nearly all suspended yeast, and become comparatively bright and ready to run down into the "chip cask" cellar in from twenty-five to thirty days.

In the chip cask cellar the beers are finished off for consumption, and it is kept at a temperature of about 40° to 41° F., the casks themselves having a capacity of from 50 to 100 barrels. The chip casks are coated inside with pitch, and their bottoms are strewn with a good layer of clean cedar chips, which are changed and carefully washed each time the casks are emptied. These chips (which give their name to the casks) are added in order to provide surfaces of attraction for the deposition of the yeast. The casks are filled by first introducing mature beer from the storage cellar to about half their capacity; then putting in about 12 or 15 per cent. of fresh young beer (thirty-six hours old), and then topping up with storage cellar beer. The specific gravity of the total cask contents is thus brought up to about 1·021, and after adding a small quantity of finings made from isinglass, the casks are closed and an automatic bunging apparatus is adjusted and regulated at a pressure of about 6 pounds per square inch. The beer now commences to undergo a second and final fermentation, and impregnates itself with carbonic acid gas under pressure. In about fourteen days, when it is ready for racking, it is run off through a filter into the trade packages, and is then immediately sent out for consumption.

When beers are intended for export they are invariably pasteurized. After being racked off and bottled, they are placed in a water-bath, gradually heated to a temperature of 152° F., held there for thirty minutes, in order to paralyze all living organisms, and then as gradually cooled down to

the normal temperature. They thus remain sound and perfectly brilliant for a very long period, and may be safely exported to hot climates, without deterioration or change.

As it was not my purpose at the outset to enter into explanatory details of mere practical processes of brewing, which can only interest those who are engaged in the art, and as my only object is to show you in what unlimited measure the march of science has influenced the development of modern beer brewing, I may turn away from any further consideration of the methods by which beers are actually produced and proceed to a more critical examination of the two beers which we have made here this evening, and of which I deeply regret my inability to produce material samples for your criticisms.

Referring to the tabulated results of the two worts, you will please remember that No. 1 was made from malt and hops only, while No. 2 was made from a mixture of malt and corn grits and hops. You will, therefore, be interested to study the analyses of the finished beers from these two brews, as sent out for consumption by the public:

	No. 1.	No. 2.
Original specific gravity	1·053	1·053
Specific gravity of finished beer	1·013	1·017
Carbonic acid gas	0·35	0·37
Absolute alcohol (by weight)	4·20	3·49
Volatile acidity (as acetic acid)	0·003	0·002
Total residual unfermented solids	4·67	6·39
Unfermented sugar in total solids	1·35	1·80
Total fixed acidity (estimated as lactic acid)	0·14	0·13
Proteids or nitrogenous matter	0·53	0·38
Ratio of sugars to non-sugars in total unfermented solids	1:2 50	1:2·55
Ash	0·20	0·19
Degree of fermentation	64 p. c.	54 p. c.

It is, of course, a very difficult matter for the uninitiated to grasp all the significance of these figures, but I am vain enough to hope you will be able to agree with me in the following interpretation of them:

(1) The character of the actual component parts of both beers, made in the one case from malt and hops only, and in

the other from a mixture of malt and raw grain and hops, is identical.

(2) The differences in their composition or in the arrangement of their components are only those which we knowingly created, first, by restricting the action of the diastase, and thus producing less fermentable matter in the wort, and less alcohol in the finished beer; and, second, by decreasing the amount of soluble proteids, and thus diminishing the liability of the beer to subsequent fermentative changes.

Do not these analyses make it clear to you, when taken with all the other things I have laid before you, that the modern scientific brewer should have a sufficient knowledge of his art to change at will the nature of his beers? Does it not appear to you that he can foretell with sufficient accuracy what result he is going to obtain from the use of any process he may deem it advisable to adopt, in order to fulfil any reasonable demand made upon him by a variation in public taste? What has he to do in order to produce beers that will be satisfactory from all points of view? He must see to it that his worts contain:

(1) The proper proportion of readily fermentable sugars.

(2) Certain other sugars and non-sugars which do not so readily ferment, but which are included in the "unfermented extract" of beer, and contribute to "roundness" or "mellowness."

(3) Free dextrine, which is quite unfermentable by the true beer yeast, and constitutes the bulk of the unfermented extract.

(4) A certain amount of free acidity, which I have estimated in my selected analyses as lactic acid, for the sake of convenience, but which really is largely made up of acid phosphates.

(5) The proper proportion of saline matters derived from the water, the malt and the hops, and mainly composed of phosphates, sulphates and chlorides of calcium and potassium, all of which are necessary as yeast food, and some of which contribute to the permanent solubility of the nitrogenous or albuminous matter of malt.

(6) The proper proportion of the nitrogenous bodies themselves, mainly made up of albumoses, peptones and amides.

The modern brewer knows, because science has taught him, that the main portion of the soluble nitrogenous bodies in malt serve as food for the yeast; and, as you yourselves can see by comparing my analyses of worts with those of the finished beers, they are partially eliminated by the yeast during the fermentation. Those which are not so eliminated impart nourishing qualities to the beer, and give it a round, full-mouthed taste and good foaming capacity. One of the great sources of trouble with them has ever been that their solubility, especially those of the albumose and peptone types, is constantly being affected by the chemical and physical changes undergone by the wort during the progress of its fermentation. Thus, for example, some of them fall out of solution as soon as alcohol commences to be formed, and the degree of their insolubility is coincident with the increase of the alcohol. Others, while perfectly soluble at normal temperatures—say, for example, at 50° F.—become insoluble as the temperature is lowered. For every downward variation in temperature a succession of them is precipitated, until the maximum is reached at or about the freezing point of water.

We may take a beer that is perfectly brilliant at 50° F., and find that upon being cooled to 40° F. it will become cloudy. If, after filtration, it is again cooled down to, say, 35° F., a fresh cloudiness will manifest itself; and so we may go on filtering and cooling for every successive drop in temperature, until the final precipitation point is reached.

In times gone by, when science was a myth, beers were kept in cold storage for many months, because when they were not so kept they readily became cloudy when sent out from the brewery, if they were placed on ice. The ice machine had not been invented; the cellars were imperfectly cooled by the use of natural ice, and the beers had to cool down spontaneously in the big storage casks. The mere fact that modern chemical invention now enables us, at the end of the primary fermentation of the beers, to rapidly re-

duce their temperature down to any required point by passing them through efficient coolers, and thus to immediately precipitate such forms of nitrogenous matter as are removable by cold, does away with the *necessity for prolonged cold storage*, and this of itself would have marked one of the most important steps in the advancement of brewing.

And now, ladies and gentlemen, if I have not tired you with unnecessary scientific details, and have made my attempted exposition partially clear and intelligible, you must have gained the conviction that chemistry and science generally have indeed done their share in promoting the advancement of this important branch of the industries of fermentation. I have already given you some statistics and bothered you with a great many figures, but I feel compelled to further trespass upon your indulgence in order to cite a few more.

According to the figures which I have gathered from official sources, the total production and sale of malt liquor in the United States in the year 1863 was 2,600,000 barrels; and, from my careful inquiry into the progress made in subsequent years, I find figures that are well-nigh incredible.

In 1868 the sales amounted to	. . . . .	6,147,000	barrels.
" 1873	"	"	"	"	. . . . .	9,634,000	"
" 1878	"	"	"	"	. . . . .	10,242,000	"
" 1883	"	"	"	"	. . . . .	13,500,000	"
" 1888	"	"	"	"	. . . . .	24,600,000	"
" 1893	"	"	"	"	. . . . .	33,800,000	"
" 1898	"	"	"	"	. . . . .	37,500,000	"

If I am creditably informed—as I believe I am—the cash capital actually invested in the brewing industry in this country now exceeds the sum of $250,000,000. The yearly value of the product made and sold is very approximately $225,000,000. The revenue collected from the brewers by the United States Government is closely in the neighborhood of $70,000,000 per year.

These are formidable figures, and I find in them ample justification for my preliminary statement of the benefits which have accrued to this industry from its alliance with science. To claim that chemical science has worked all

these wonders by itself would be, of course, unfair; and it is far from my desire to deprecate the contributions of mechanical engineering.

At the present time the interests of science and of practice are regarded as identical, but they have not always been so considered. It is not so many years ago that purely practical brewers and "masters of the mysteries" were prone to scoff at the theories of what they called "the beer doctor;" but the march of technical education has naturally reacted in the chemists' favor; and it is a fact which I am proud to place on record, that there is no more welcome or honored guest in the brewery of to-day than the chemist and biologist. If the theories that are worked out in the laboratory are at first regarded with doubt and suspicion, they are eventually put to the test in the brewery on the industrial scale; and as they thus carry conviction, every advance in scientific discovery is accompanied by a corresponding movement in the industry whose welfare we are working to promote. On the other hand, it is quite obvious that with every step forward that is taken by the practical industry itself, fresh fields for investigation are opened up for the scientist; and thus the growth of the science and the industry are made dependent upon each other; and they must consequently be ever wedded and pass on happily, in the paths of progress, hand in hand.

RECAPITULATION OF IMPORTANT DATA EMBODIED IN THIS PAPER.

Comparative Table of the Composition of the Cereals Used by Modern Brewers in the Brewing of Modern Beers.

	Malt.	Corn Grits.	Rice.	Barley.
Moisture	4·00	10·50	10·60	12·00
Starch, sugar and gum	68·00	76·40	81·00	60·00
Fat	2·25	0·65	0·10	2·50
Nitrogenous matters (soluble)	4·00	0·00	0·00	0·00
Nitrogenous matters (insoluble)	8·00	11·00	7·20	12·00
Mineral matters	2·25	0·45	0·90	2·50
Cellulose or husk	11·50	1·00	0·20	11·00

Necessary Determinations to be Made by Chemists in the Analysis of Brewing Water.

(1) Hardness before boiling.
(2) Hardness after boiling.

(3) Total solid residue after evaporation.
(4) Residue after calcining the above at low red heat.
(5) Bases and acids.
(6) Free ammonia.
(7) Albuminoid or organic ammonia.
(8) Oxygen required to oxidize the organic matter in five minutes at 80° F.
(9) Oxygen required to oxidize the organic matter in 3 hours at 80° F.
(10) Nitrous acid or nitrites.
(11) Nitric acid or nitrates.

SUBSTANCES ENTERING INTO THE COMPOSITION OF BREWERS' WORT.

Maltose.
Malto-Dextrines.
Dextrines.
Albuminoids or Proteids.
Mineral Salts.

TABLE SHOWING THE AMOUNT OF MALT ADJUNCTS THAT WILL YIELD AS MUCH EXTRACT IN THE MASH-TUB AS ONE BUSHEL OF MALT.

Twenty-seven and one-half pounds flaked corn.
Twenty-six and one-half pounds rice.
Twenty-six and one-half pounds grape sugar or glucose.
Twenty-nine pounds corn grits.

TABLE SHOWING THE DIMINISHING INFLUENCE OF HEAT UPON DIASTASE DURING THE KILNING OF MALT.

Temperature.	Moisture.	Diastasic Power.
140° F.	7·00	168
150° F.	5·00	145
160° F.	4·20	120
175° F.	3·10	105
190° F.	2·05	87

COMPLETE TABULATION OF A BREWING IN WHICH THE WORT IS BREWED FROM A MIXTURE OF MALT AND RAW GRAIN AND HOPS AND IS TO PRODUCE A "FULL-BODIED," NON-VINOUS BEER.

Quantity of wort required in fermenters	200 barrels.
Gravity of wort in fermenters, when cold	1·053
Ratio of fermentables to non-fermentables	1:0·51
Conversion temperature is to be	158° F.
Proportion of total water to grist is	6¼ to 1
The water for the malt mash is at	120° F.
Proportion of water to malt for the malt mash is	2·50 to 1
The raw grain mash is to be boiled	212° F.
The raw grain is mixed with 50 per cent. of its weight of malt.	
The proportion of water to the total grist in the raw grain mash is	2·50 to 1

Temperature of the water in the hot-water tank, to be used in the underflow of the mash-tub to bring up the temperature of the entire mash to the desired point at which it is to rest, is	212° F.
The final resting temperature of the mash	164° F.
The total amount of sparge water is of the total water to be used	58 per cent.
The temperature of the sparge water is	1166° F.
The tap heat throughout the run is	158° F.

COMPOSITION OF A WORT BREWED FROM MALT AND HOPS ONLY AND DESTINED TO PRODUCE A VINOUS BEER (No. 1).

Specific gravity at 60° F.	1·053
Total solid extract (by weight), per cent.	13·37
Fermentable sugars in extract (estimated by Fehling's solution as maltose)	9·75
Proteids or nitrogenous matters (suitable as yeast food)	0·74
Total acidity (estimated as lactic acid)	0·14
Ratio of fermentable matter to the other bodies in the extract not fermentable	1:0·37
Ash (phosphates, etc.)	0·22

COMPOSITION OF A WORT BREWED FROM MALT, RAW GRAIN AND HOPS, DESTINED TO PRODUCE A "FULL-BODIED," NON-VINOUS BEER (No. 2).

Specific gravity at 60° F.	1·053
Total solid extract (per cent.)	13·37
Fermentable sugar in extract (estimated by Fehling's solution as maltose)	8·80
Proteids or nitrogenous matters (suitable as yeast food)	0·53
Total acidity (estimated as lactic acid)	0·12
Ratio of fermentable matter to the other bodies in extract not fermentable	1 : 0·52
Ash (phosphates, etc.)	0·19

TABLE OF COMPARISON BETWEEN THE FINISHED BEERS RESULTING FROM THE FERMENTATION OF WORT No. 1, MADE FROM MALT AND HOPS ONLY, AND WORT No. 2, MADE FROM MALT, RAW GRAIN AND HOPS.

	No. 1.	No. 2.
Original specific gravity	1·053	1·053
Specific gravity of finished beer	1·013	1·017
Carbonic acid gas	0·35	0·37
Absolute alcohol (by weight)	4·20	3·49
Volatile acidity (as acetic acid)	0·003	0·002
Total residual unfermented solids	4·67	6·39
Unfermented sugar in total solids	1·35	1·80
Total fixed acidity (estimated as lactic acid)	0·14	0·13

Proteids or nitrogenous matter	0·53	0·38
Ratio of sugars to non-sugars in total unfermented solids	1: 2·50	1: 2·55
Ash	0·20	0·19
Degree of fermentation	64 p.c.	54 p.c.

TABLE SHOWING THE INCREASE IN THE PRODUCTION OF MALT LIQUORS IN THE UNITED STATES, FROM THE YEAR 1863 TO 1898.

In 1868 the sales amounted to	6,147,000	barrels.
In 1873 " " " "	9,634,000	"
In 1878 " " " "	10,242,000	"
In 1883 " " " "	13,500,000	"
In 1888 " " " "	24,600,000	"
In 1893 " " " "	33,800,000	"
In 1898 " " " "	37,500,000	"

Franklin Institute.

[*Proceedings of the stated meeting held Wednesday, September 19, 1900.*]

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, September 19, 1900.

Vice-President THEO. D. RAND in the chair.

Present, 128 members and visitors.

Additions to membership since last report, 22.

The Secretary read a letter from President Birkinbine, expressing his regret at not being able to be present at the opening meeting of the season, and calling attention to the need of active co-operation on the part of the members in behalf of the Endowment Fund of the Institute and for the increase of the membership.

The presiding officer introduced Mr. Fred. W. Unger, of Philadelphia, who had recently returned from the scene of the war in South Africa, where he had been engaged as war correspondent for several prominent English journals. Mr. Unger gave an interesting description of the military operations of the Boer-British conflict, dwelling specially on the engineering features of the subject.

Prof. Arthur J. Rowland, Drexel Institute, Philadelphia, presented a paper entitled "Mistakes in the Rating of Incandescent Electric Lamps," in which he gave the results of his investigations respecting the useful light-emitting efficiency of the different types of incandescent lamps. The paper was discussed by Dr. Geo. F. Stradling, Mr. W. C. L. Eglin, Dr. Francis Head, and the author. (Paper and discussion will be found in this impression of the *Journal.*)

Mr. W. N. Jennings exhibited and commented on several lightning photographs which he had taken, and the meeting was adjourned.

WM. H. WAHL, *Secretary.*